RADICAL MYCOLOGY

A Treatise On Seeing & Working With Fungi

Peter McCoy

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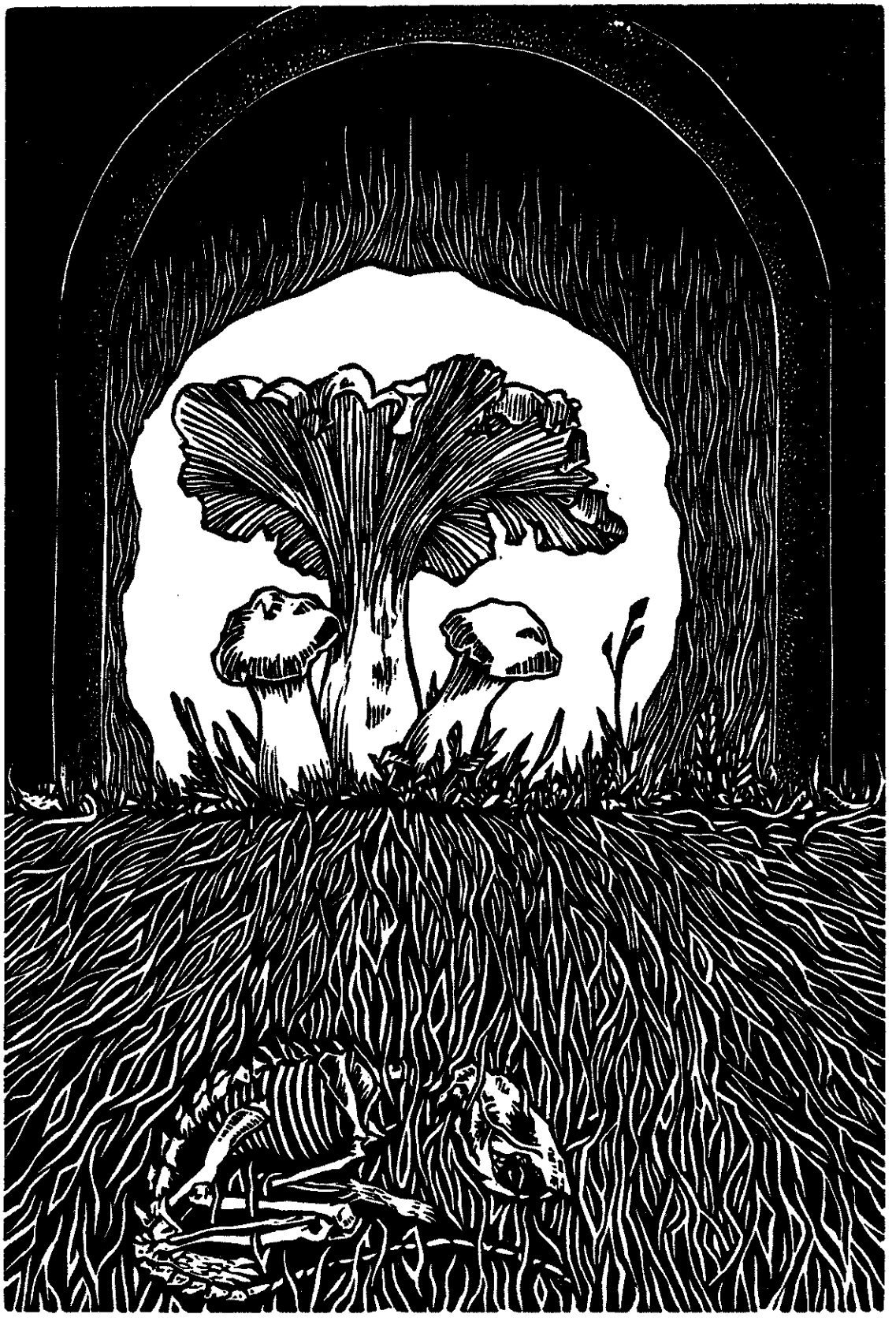

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PETER MCCOY

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Dedicated to my mother,
written for the fungi.

PREFACE

***MYCOLOGY**: The study of fungi (e.g. mushrooms, molds, yeasts, and lichens).*

***RADICAL MYCOLOGY**: 1) A social philosophy that describes cultural phenomena through a framework inspired by the unique qualities of fungal biology and ecology. 2) A mycocentric analysis of ecological relationships. 3) A grassroots movement that produces and distributes accessible mycological and fungal cultivation information to enhance the resilience of humans, their societies, and the environments they touch.*

In 2006 I was living in Olympia, Washington, a mushroom-steeped city in the heart of the Cascadia bioregion. For years I had been cultivating fungi and studying their habits. But it wasn't until I became deeply involved in the art and activist movements of Olympia that I found the language and skills to further develop ideas I had long held on how to integrate fungi into any social movement or way of life. Working with my friend Maya Elson, these initial concepts were further elaborated upon until, in 2008, I put them down in a self-published zine, or booklet, entitled *Radical Mycology*. Considering that at the time I only knew one or two friends interested in blending fungi with politics and art, I assumed that nobody beyond a few people would be interested in reading the text. I couldn't have been more wrong.

In the years since its initial publication, the Radical Mycology zine has spread around the world through a network of countless mycophiles, activists, and DIYers. As the text's proposals increased in familiarity, Radical Mycology turned from an idea into a practice and quickly evolved in ways that I could have never imagined. Along with other Radical Mycologists, I have organized three internationally attended, volunteer-run, and donation-based Radical Mycology Convergences. These events bring together teachers, activists, and ecologists passionate about sharing their knowledge around fungi in an open source and collaborative format. Such an approach is distinct from the identification-focused and afternoon-long format of most traditional mycological events. In 2014, the Radical Mycology Collective toured North America to share mycological knowledge and skills with over 40 artist and activist groups and to demonstrate how mycology can support all aspects of life. Along the way, various Radical Mycology groups have started across the United States to share their knowledge and passions for fungi with their local community—*to spread their spores*. Throughout this long journey, I have been inspired by and worked with countless artists, food justice advocates, permaculturalists, fermenters, homesteaders, independent media makers, grassroots bioremediators, herbalists, natural medicine practitioners, musicians, poets, ecologists, Earth stewards, and social critics.

This book is the summation of those innumerable discussions and projects. It is a resource by which Radical Mycology as both theory and praxis can be readily placed into the hands of anyone working to enhance their home or community. To my surprise, I found during the writing process that in order to fully reflect the array of cultural intersections that fungi form, connections needed

to be drawn between mycology and a variety of other fields—from ecology, to history, to sociology. While some of these intersections are readily apparent, many others take time to see clearly. Uncovering all of them has been a personal odyssey through the cycles of life, with each turn expanding, enriching, and testing my worldview in ways I never anticipated. To the best of my ability, I have transcribed these insights in hopes that you may experience some of this rich perspective—a wisdom that only the fungi can fully teach.

Radical Mycology begins with an introduction to the state of mycology as a science and the importance of increasing mycological awareness in Western cultures. Chapter 1 explores the many forms and unique characteristics of fungal biology. With these terms covered, Chapter 2 dives into the vast importance of fungal ecology, with an emphasis on their centrality in the maintenance of plant and animal health. Chapter 3 then presents an overview of the major influences fungi have had in human cultures, a theme that develops throughout the rest of the text.

Chapter 4 addresses how to identify macro and micro fungi for personal benefit as well as to support conservation efforts. Chapter 5 covers the incredible qualities of lichens, as written by lichenologist Nastassja Noell. Chapter 6 explains the importance of fungi in foods and drinks as well as how to cultivate fermenting fungi. And Chapter 7 presents the medicinal history of fungi along with recipes for making potent fungal medicines.

Chapter 8 covers the intricacies of high-quality, "lab-based" fungal cultivation, with a special emphasis on growing fungi with few inputs, low costs, and little difficulty. Chapter 9 takes the skills learned in Chapter 8 outside to show how fungi can and should be added to any integrated and holistic living system. With these cultivation skills addressed, Chapter 10 provides a thorough examination of the burgeoning science of mycoremediation, including an explanation of the chemistry involved and protocols for common pollution scenarios.

Chapter 11 interprets fungal intelligence through a socio-political framework by discussing how many qualities of fungal biology and ecology can influence the development of intelligent and resilient human societies. Chapter 12 concludes the main text with a thorough conspectus on the history and social influences of psychoactive fungi. To close, over 100 species profiles and 17 appendices are included to fill in the last pieces of the mycopuzzle. With such a diverse collection of information, this book will enable anyone to easily bring the many gifts of the fungi into their lives.

How to Read This Book

The information in *Radical Mycology* builds sequentially. As such, it is meant to be read from cover to cover. Commonly discussed mushrooms are referred to by their common English name in North America. Uncommon mushrooms that are only mentioned occasionally are referred to in their Latin binomial. If you are not sure which species is being referred to, check the species listed in Appendix G and in the Species Profiles sections to find its binomial.

ACKNOWLEDGEMENTS

Though this book is the summation of my life's work with fungi, it would not have been possible without the extensive help, support, inspiration, and encouragement provided by innumerable friends, collaborators, and mentors. To the Radical Mycologists, activists, culture jammers, critical thinkers, social critics, foodies, rad herbies, DIYers, street artists, travellers, visionaries, permies, punks, and poets I have encountered over the last decade, I thank you all for weaving into my web of experience.

Of special note, I endlessly thank Willoughby Arevalo for his significant contributions to this book's identification information and for his priceless elaborations on numerous concepts presented throughout the text. I thank Mara Penfil for her exceptional help in editing and designing this book and for being such a wonderful friend. I am indebted to Beverly and Steve Smith for their extensive help with many of the tedious aspects of data entry and editing. I thank Maya Elson for all her help building Radical Mycology from a vision to a reality. I thank James Weiser for sharing a wealth of information and insight into the cultivation process over the years. I thank the countless anonymous researchers and administrators of Mycotopia and Shroomery for their significant contributions to the advancement of DIY mycology. I am grateful for the feedback from Dr. Gerald Pollack on *The EZ Theory of Hyphal Extension*, for the help from Jim Bell and Joshua Kogan on the technical details of soil mechanics and remediation, and for Marlene at Tumbling Creek Farm's insights into biodynamic mushroom cultivation. I thank Jan Irvin for sharing his research and time with me. I also thank Willoughby Arevalo, Ava Arvest, Stephen Buhner, Willie Crosby, Maya Elson, Jackie Goordial, Geoffroy Grignon, Fern Katz, Nastassja Noell, Mara Penfil, Rowan, Jason Scott, Peter Sjöstedt-H, Joseph Soeller, Jackson Tegu, and Bonnie Rose Weaver for making such wonderful contributions to this book. Likewise, I thank all the photographers who have made their beautiful images in this book available to the creative commons.

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Introduction

Toward a Radical Mycology

Humankind has not woven the web of life. We are but one thread within it. Whatever we do to the web, we do to ourselves. All things are bound together. All things connect.
—*Chief Seattle, 1854*

All life is interconnected. This is the primary lesson that fungi teach. Through their mycelial networks—those decentralized webs of white tissue often found beneath logs and rocks—mushrooms and other fungi permeate the world, connecting and turning its innumerable cycles to demonstrate that every act carries an immeasurable chain of effects. Possessing traits and abilities not found amongst plants, animals, or other microbes, fungi fill unique roles in the stewardship and evolution of Earth. And as builders of the soil web and grand healers of the land and sea, they lie at the heart of the world and offer a perspective that cannot be equated.

Through the mycelial lens, the haste of modern human life slows, exposing Nature's most refined principles, which our ancestors understood so well. When one offers the fungi time for study, even their smallest moments expose lessons on how to embody these principles, and thereby find new means for respecting and connecting with the natural world. Along with these insights, the benefits of integrating fungal cultivation into daily life can enhance the design of one's home and town in ways that are more supportive of the culture and environment at large. To those able to see them clearly, the fungi offer these and many other vital gifts.

Working with fungi is not a new chapter in the human story, but an ancient relationship woven into our foods, medicines, and customs. They are the world's greatest and oldest teachers, timelessly spawning a wisdom that can just as readily uplift habitats as unite a community. Many of their solutions are practical; others are philosophical. But considering the youth of mycology, all of their offerings present an untold potential for enhancing the health and resilience of any living system.

A Neglected Megascience

Two facts become quickly apparent for anyone studying mycology: 1) fungi are incredibly important and fascinating and 2) nobody knows about number 1. For no clear reason, fungi have been largely dismissed amongst westerners—a mere oddity to be feared and forgotten. Whereas plant growth and the concept of "germs" and bacteria are taught to children at a young age, mycology is essentially absent from grades K–12 and above. Even at the graduate level, when fungi are presented in natural science courses it is often with a cursory assessment that emphasizes their misunderstood actions as "pathogens." With minimal representation in the media, this mycological knowledge gap tends to remain in place outside of one's schooling, leaving many westerners uninformed and unaware[1] of the untold potential that mycology offers. Thus, as those in the west never hear, learn, think, or talk about fungi, these organisms become increasingly easy to ignore and buried beneath layers of maligned mystery.

In the academic world, this problem is almost worse. Paradoxically, fungi are recognized for their ubiquity and importance amongst biologists, and yet mycology has remained a "neglected megascience"[2] throughout its short, 250-year history. Whereas most university departments are under constant threat of budget cuts, the small and scarce mycology departments in western universities face closure and a subsequent end in the transmission of local mycological knowledge. While it is notable that countries such as China, Mexico, and Brazil are contributing a significant amount of contemporary research into mycology, the majority of living and dried fungal reference collections, monographs, reference books, and key databases are still found among the declining mycological institutions of North America and Europe. In effect, the higher levels of mycological information remain tenuously locked in expensive textbooks and scattered classrooms, inaccessible to the vast majority of the world.

Where university departments do remain open, traditional whole-organism mycology has largely fallen by the wayside in the advent of genetic analysis. As research increasingly focuses on deciphering code on a computer, the tangible ecological roles of fungi, along with their field identification, loses further visibility amongst academics. Such a trend threatens many other naturalist-dependent subjects, including mammalogy, ornithology, ichthyology, herpetology, entomology, bryology, and taxonomy of vascular plants. But though these fields hold many unanswered questions, the poverty in mycology relative to its potential importance suggests that it is one of the biggest information gaps—if not *the* biggest—in the natural sciences. So as the field shrinks and elder top-level mycologists retire, the future of their knowledge and resources—and western mycology as whole—becomes increasingly insecure and at risk of ending before it has truly begun.

The Smallest Spore

Looking at many trends in the sciences, it is clear that the decreased emphasis on whole-organism research in mycology and other fields is not simply an effect of advances in technology, but of underlying assumptions that permeate the scientific community and western culture in general. Compared to the interdisciplinary approach that fueled the research of many of history's great scientists, today the sciences are increasingly fragmented and largely unfamiliar with the finer details of each other's work. Many researchers in universities are so specialized within a tiny subset of their overarching department that it is difficult for them to be well-versed in the intricacies of other research projects in their department, let alone other departments, universities, or the scientific community at large.

This splintering has not been intentional amongst scientists, but has come about as the result of the *reductionist* scientific model, which attempts to understand the world by analyzing its smallest parts. Though this model has arguably created an efficient, assembly line style approach to gathering information, it has largely left behind the importance of connecting the dots that each field uncovers. In effect, reductionism is a double-edged sword, with greater knowledge accumulating on one side and incoherence spreading across the other.

As this trend proceeds, those uneducated in the sciences are left with few resources to easily

validate a given field's latest finding or to determine if it is considerate of the multiple other sciences and natural phenomena it may influence or be influenced by. This double-checking amongst *citizen scientists* is needed, for if a given conclusion is not holistic in its analysis, it may be used to justify public and private policies with unforeseen and potentially detrimental effects. And yet, such validation efforts are demanding as a thorough investigation of a given subject implies sorting through a large amount of scientific literature written in inaccessible language and contained within expensive journals and databases. With little time to interpret and integrate this data—let alone develop a rigorous interdisciplinary review—the average person becomes more inclined to leave its analysis to the experts.

Even amongst top-level researchers, problems can be created due to the reductionist method. The splintering of knowledge often creates nuanced, field-biased perspectives that can lead to conflicting interpretations of data sets, common phenomena, or the larger meta-systems that govern the details researchers pick apart. Such discrepancies may remain unresolved for years, even amongst experts in the same field. This is especially common when new findings contradict longstanding models. In many instances, scientists well-versed in an accepted theory will reject a radically new paradigm—regardless of its logical or empirical validity—simply because the new model goes against what has long been taught.

In effect, the whole of science moves forward slowly, often at the rate at which one generation replaces the last one and updates the textbooks. In the interim, challenging research is unable to gain a seat at the theoretical bargaining table, leaving the uninformed non-scientific community to model their worldview with potentially outdated paradigms. In the globalized culture afforded by the internet, this continuity is further reinforced by the coverage and acceptance that some theories obtain, regardless of their lack of rigor or potential long-term impacts on the health of a people or the planet.

Where to Look?

The cultural effects of such a narrow perspective are many. By presenting the world as a collage of fragmented subjects, the connections between ideas, humans, and the environment become increasingly difficult to perceive. Reductionism creates an unnatural separation effect in the mind in which objects and topics that are inextricable from one another in the real world can be intellectually split apart. In the sciences, this enables humans to act as though they are separated from Nature by attempting to study it from the outside. For the culture at large, reductionism can justify actions that imply human superiority over the rest of the world, an anthropocentrism in which exploitation of the environment can be interpreted as a necessary act.

Over time, the heavy-handed voice of reductionism comes to drown out traditional perspectives, customs, and cultures. While at the same time, the fast tracking of social, environmental, and economic models codified by science increases the potential for flawed theories to slip through the cracks of intellectual filters. Though some of these new models may come from well-intentioned scientists and policy makers, others may be devised by commercial ventures seeking to replace the fading customs with an imposed culture based on consumerism and the unsustainable extraction of natural resources. Such imposed cultures tend to reinforce the reductionist mindset that enables them to flourish, often with an increased dependence on technologies that reduce necessity for the direct transmission of knowledge or other real world interactions. In the end, an unnatural framework is built into the mind of humanity, one in which the universe can be seen as a machine, forests can be replaced with monocultures of chemical-dependent crops, and fungi can be rejected for a lack of any apparent value.

When a culture becomes fragmented, the potential develops for its structure to be reinterpreted and its pieces repositioned. Such redefining of society occurred when cultural theorists and global oligarchs used Herbert Spencer's (1820–1903) interpretation of Darwin's evolutionary model to describe society as nothing more than a struggle for the "survival of the fittest." Through the reductionist mindset, this interpretation was used to justify the segregation and separation of people from each other as well as through imposed degrees of rank. The resulting concept of

"social Darwinism" was later used as a scientific justification for class divisions, anthropocentrism, hierarchical governmental structures, and the rise of neoliberal free market economics in which only the strongest survive.

Such unnatural human-designed models quickly lose validity through a study of the ecological roles of fungi. Just as anarchist philosopher Peter Kropotkin (1842–1921) pointed out nearly a century ago, the concept that life is a constant fight for the next rung in the evolutionary ladder is contradictory to the everyday experience of Nature. Communication and collaboration amongst animals, plants, and microbes is vital to the health of each individual as well as to the entire ecosystem on which they all depend. As the natural world's grand connectors, mycelial networks exemplify this universal principle of mutual aid. They act as a clear model for connecting communities and ideas to help reverse the problems of reductionism. For though reductionism provides valuable and unique means for measuring the world, it is, like all belief systems, inherently lined with limitations, unexamined assumptions, and design flaws. To complement its benefits, reductionist frameworks must be balanced by the insights provided by alternative modes of learning.

This is no small order. Acceptance of the reductionist model has become so fundamental to modernity that its vast influence is largely invisible—a form of conditioning that hides in plain sight. Indeed, to even question its infallibility is likely to receive mockery and condemnation from people within and outside of the scientific community. But to hold close to reductionism, or any belief system, automatically precludes the ability to consider opposing views. And as one becomes increasingly affirmed in a singular mode of thinking, they also tend to become decreasingly tolerant of alternative perspectives, an inverse relationship that is inherently self-limiting to one's intellectual freedom.

When we confront the foundations of our systems of learning and challenge the assumptions that underlie the design of culture, new opportunities for engagement between people and their environment are found waiting. Windows into the world's unlimited potential open, revealing that mediation of experience is untenable and the only limiting factor to innovation is creativity. Indeed, experimentation is always needed to find better alternatives. Without risk-taking, we'll never discover what's possible. Just as any historian of science knows, major advances in science are not made in small steps, but by leaps and bounds that are largely guided by intuition, chance, and a willingness to challenge dogmas. Often, these shifts come about by curious hobbyists. As Aristotle once stated, "It is the mark of an educated mind to be able to entertain a thought without accepting it." Or, in other words, one should be both skeptical and open-minded, just not so open-minded that their brain falls out.

Just as many of history's greatest civilizations have likely thought of themselves as the pinnacle of existence only to later collapse,[3] so too must the superiority of reductionism as an epistemological model be amended, lest it topple under the weight of its own assumptions. Ultimately, there are many facets of the universe that humans cannot measure, have no conception of, and will never understand, a fact that questions the very notion that one can truly come to know anything. The willingness to be humble in the face of such mystery is perhaps the greatest challenge in the scientific community, where many suffer under what cosmologist Hermann Bondi referred to as the "lure of completeness": a craving for certainty that leads to irrational and blind dogmatism.[4] Such shortcomings must be overcome by all who wish to develop new cultural paradigms that recognize, honor, and integrate the patterns and principles of Nature—laws of the universe that fungi express completely. This is not always an easy process but, as when overcoming any challenge, often results in many unforeseen and far-reaching positive effects.

Mycology for the New Millennium

In the field of mycology, this open-mindedness is crucial. As one of the youngest natural sciences, discoveries are constantly being made about fungi that dispute long-held beliefs. As this science continues to develop over the coming decades, mycologists entering the field must recognize that this limited understanding of fungi provides anyone with some degree of training the unique opportunity to significantly add to this growing knowledge base. Unlike most sciences, mycology is

one of the few fields that the citizen scientist can actively contribute to.

Over the last 50 years, the major interface between academic mycology and the general public in North America has been through the devout efforts of amateur (from the Latin *amare*, "to love") mycological societies. During that time, these stewards of knowledge have significantly helped maintain public interest in mycology amongst westerners, while also spawning generations of committed field mycologists. Today, mycological societies are making concerted efforts to document the ecology and distribution of macro fungi (mushrooms), a valuable form of citizen science that almost anyone can support. But as these efforts heavily rely on the support of mycology departments in universities and botanical gardens, mycological societies also face a degree of insecurity due to the tenuous state of their supporting institutions. And with few resources for learning about fungi beyond mushroom identification readily available, many become disheartened to discover that, apart from the information provided by these societies, there is no easy means for becoming a mycologist—there is no royal road to mycology.

It is for this reason that the Radical Mycology project developed a decade ago: to create a people's mycological movement that is not only versed in the cultivation of fungi and the applications of mycology, but also in how to actively and significantly contribute to the advancement of the science as a whole. Whereas humans have been cultivating plants and tending animals for at least 10–12,000 years, mushroom cultivation only began around 2,000 years ago in China. Refined, lab-based practices developed less than 100 years ago, and some of the advances in kitchen-based cultivation described in *Radical Mycology* are less than a decade old. Further, these developments in home mycology have made the science more accessible and less dependent on expensive and centralized technology than ever before.

With such an exponential growth in our ability to work with fungi, it is impossible to imagine where this field is heading. To keep such potential inaccessible—or worse yet, to limit the variety of perspectives with which to view fungi—is an imposed cultural limit that stifles the health of current and future generations. Just as when electricity was first discovered and no models existed to explain its novel phenomena, so too will the mycologists of today be central in the creation of unprecedented paradigms for not only understanding fungi, but also the individuals, ecosystems, and life cycles that fungi sustain.

Along with various practical skills, the Radical Mycology perspective presents means to thoroughly integrate the habits of fungi into one's way of being. Fungi challenge us to look beneath the surface, live on the edge, explore the unknown, adapt, respect imperfections and differences, and to always look for another way forward. Through the mycelial lens, one can regain the ability to see the world as a whole derived from various influences and perspectives—different branches in the network assessing hidden bonds. As one learns to see innumerable connections in the world, the tools for addressing complex challenges can no longer be placed in isolation, just as perspectives of seemingly opposing forces can be found to complement one another, especially when both seek remedy in the world.

Radical Mycology is thus a mycocentric approach to building the three major pillars of social change: education and awareness building around important issues; resisting, slowing, and stopping ineffective or disastrous social systems; and designing functional and appropriate alternative systems that increase quality of life. Through enacting these facets, Radical Mycologists stand as a voice for the Earth and for the fungi. Such acts help reduce the disempowering guilt that can come from participating in western culture's luxuries. Instead, Radical Mycologists spread the *mycopsychology* of living devoted to and bonded with Nature in a way that is affirming, intelligently self-guided, and resilient against unforeseen and inevitable change. This must be an intentional act, however. For though the fungi can show us how to grow, they cannot change the false paradigms that have steered humanity off course. Only humans can make those changes, and often only with significant effort.

Radical Mycology is therefore a solutions-based approach to tackling these challenges through a framework that is ethical, pragmatic, technical, cultural, and philosophical. By creating greater access to mycology and, to various degrees, the other sciences that mycology intersects, this text is intended to support individuals, families, communities, and social movements that actively seek a higher quality of life through prefigurative politics. To advance any social movement, an under-

Prefigurative politics: *Modes of organization and social relationships that strive to reflect the future society being sought by the group.*

standing of the various sciences that influence daily activities must be understood. As one of the most overlooked tools in the change-maker hardware store, mycology stands as one of the last uniting factors in the design of better living and social systems—a spore whose time has come.

Radical Mycologists Without Borders

Though the information in this book can be applied in a variety of ways, one of the most historically inaccessible skills presented is the means to cultivate fungi year-round on nearly any urban or agricultural waste. Fungal cultivation leads to improved management of finite resources, the production of whole foods and high quality natural medicines, greater support for local food movements and economies, job training and employment opportunities for low-income youth and urban residents, means to transform vacant tracts into productive spaces, and the ability to reduce the effects of pollution in contaminated sites. Cultivation also reinvigorates the historical connections to food that humans once commonly shared through foraging and tending crops. In effect, local mushroom cultivation systems reduce dependence on imports and the normally high cost of mushrooms, while also producing wealth, diversity, means for exchange, and the preservation of memory.

When Radical Mycologists work together to form groups, they can share these skills with various facets of their community and enhance the overall resilience of the local culture. Mycology is a uniting science, one that I am constantly surprised to find draws people from all backgrounds together. By working with strangers, neighbors, friends, and symbiotic organizations, Radical Mycologists can use their knowledge to not only increase food or reduce pollution, but they can build new intersections in their community—new mycelial webs—that string together once-distanced people across a town, bioregion, or planet.

Through these connections, greater efforts can build within the community to appropriately apply mycology in efforts of mitigating pollution in the environment to regenerate damaged habitats in both rural and urban environments—burgeoning applications of fungal cultivation that need to be refined by grassroots organizations. Such projects, along with educational workshops and forays, enable Radical Mycology groups to raise awareness around the importance of fungi as well as to place that knowledge in a context that is relatable, tangible, and overall effective in creating positive change.

To spread these benefits most effectively, Radical Mycologists must determine where their skills are most needed. This requires the ability to first identify the challenges that face present and future generations and to address them in a manner that is critical and honest as well as constructive and inspiring. Once a problem has been articulated and its terms defined, resources and skills can be drawn together to create viable alternatives and solutions. Undoubtedly mistakes will be made along the way, but by trying new models and learning-by-doing, one may discover solutions hiding where they were least expected.

Radical Mycologists of today stand on the shoulders of innumerable mycological giants, graced with the inheritance of knowledge gathered over the last few centuries and the duty to protect, honor, and build upon this fragile science. Fungi act as central agents in all cycles of life, and it is time that they begin to form a central role in all aspects of human life. As this knowledge and need ripples out, I envision teams of Radical Mycologists Without Borders travelling the globe, sharing their skills and discovering new means of working with fungi. Where one Radical Mycologist trains ten, those ten can train a hundred, and from them, a thousand—so it is that the mycelium spreads.

Thus, from this humble position on the edge of the unknown, let us now dive into the world of fungi to find that it is not a complex puzzle that can or will ever be entirely solved, but rather a place of rich complexity waiting to be experienced, explored, and embraced.

Part I

Expression

Chapter One

Chaos Fungorum

If you would understand anything, observe its beginning and its development. —Aristotle

Eternity is in love with the productions of time. —William Blake

Our exploration of the fungi begins with an appreciation of their incredible diversity. Of the 15 million species estimated to live on Earth, as many as 6 million may be a fungus.[1] Of these, only 75,000—or around 1.5% of all fungi—have been classified to date.[2] Few of these have been studied beyond their basic form and function, and less than 100 species have been significantly integrated into human activities. Only about two dozen are commonly cultivated and just seven mushroom species are grown on a mass scale, a small reflection of our limited understanding of their ways and offerings.

Fungi pervade and influence all life on Earth. Responsible for over 90% of all decomposition, they are critical in the redistribution of nutrients throughout the world. As builders of soil webs, fungi design whole ecosystems and guide the composition of a land's inhabitants. Some 2 billion years ago, fungi were the first major organisms to flourish on land. It was they who carved the way for all the plants, animals, and epochs of evolution that followed. Unseen and silent, these ever-present stewards of the wild relentlessly work to heal, support, and evolve all life on Earth. From them we have come and to them we owe the world.

With such an important history, it is difficult to understand why fungi are so commonly disregarded. Undoubtedly this is due in part to their secretive and complicated lifestyles. Many fungi defy the most advanced means of measuring and describing the world. They are hidden soil dwellers that cannot be studied in labs—underground cultures that resist control. Even the macro fungi are filled with habits and abilities that humans cannot explain. The most basic acts in the secret life of fungi are complete mysteries to those that try to unravel them, only to find that many will likely never be fully understood.

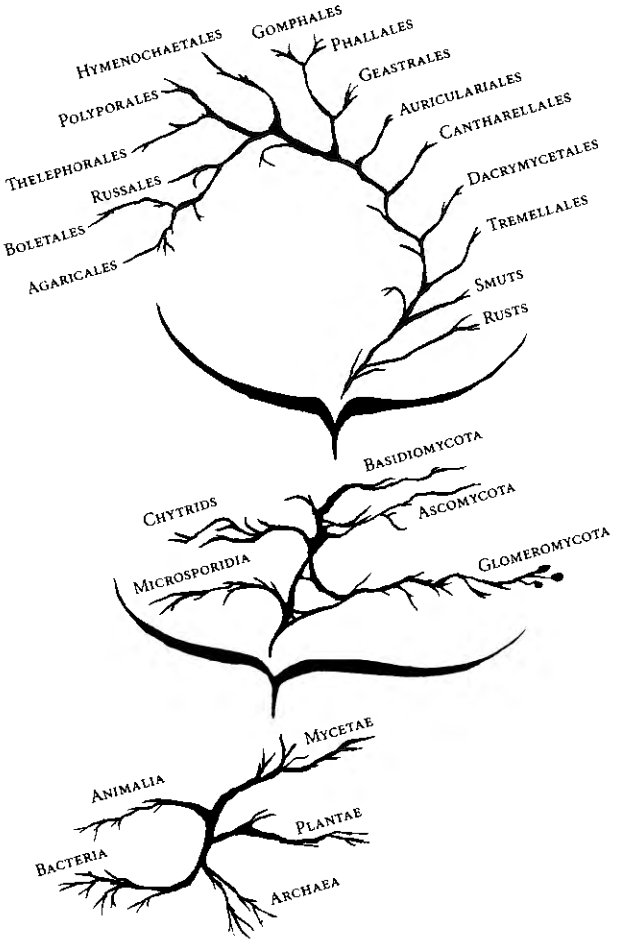
Naming Fungi

To come to know the fungi—or, at least, what they allow us to know of them—one must first learn to see and describe their many forms. Preconceived notions should be set aside in this process, at least at first. For though the fungi seem simple from a distance, examining their finer details quickly exposes vast and subtle complexities that can be readily overlooked in haste. The fungi offer many lessons into the ways of Nature. But in order to see the fungi for all that they contain, one must witness them as a child does: whole and unbound.

One of the first people to thoroughly describe and classify mushrooms was Carl Linnaeus (1707–1778), the founder of the current taxonomic naming system used to classify living objects.

For Linnaeus, the habits of fungi were so similar to that of animals that he considered them a small "animalcule" similar to worms, but in its own genus: the *Chaos fungorum*. Several decades after Linnaeus' foundations were laid in the West, Elias Fries (1794–1878) further differentiated the fungi by adding over 100 genera to the group, marking him as one of the major founders of modern mycological taxonomy.

For these men, the emphasis was on naming and sorting species. It wasn't until decades later that the life cycles and ecological roles of fungi began to gain significant attention. Even as late as the second half of the 20th century, biologists saw fungi as simple plants that did not photosynthesize. Thankfully, this error was finally corrected in 1959 when American ecologist Robert Whittaker recognized the unique traits of the *funga* as distinct from flora and fauna, and elevated the group to its own unique category: the Myceteae or Queendom Fungi.



A major branch on the web of life, the Mycetae hosts seven recognized phyla. The Basidiomycota include many well-known mushrooms that are distributed between various orders. The top level of this chart depicts the most current phylogeny of these orders.

Today, organisms are placed into the Myceteae if they retain several specific characteristics, as detailed in *The Fungal Features and Forms*. However, once they are classified as fungi, the challenge for mycologists is to then properly position and name an organism in relation to the others in the Queendom.[3]

Like a game of numbers, the perceived accuracy of a taxonomic relationship is only discernable by its comparison to other groups. Similarly, the more specimens one has to compare, the more complicated the relationships between those organisms—as well as their interpretations—can become. As more species are differentiated they can be placed together into more intelligible, namable groups. And these groups can then be placed together under larger meta-groups. And so on.

This basic classification process has not changed much since its development by Linnaeus in the 1700s, though new tools, such as DNA analysis, have been created to hasten the process. As in Linnaeus' time, taxonomic naming is largely based on Latin as it is a dead language and thus unlikely to change in coming centuries. Today, taxonomists classify organisms within the eight increasingly specific categories of Domain, Kingdom, Phylum, Class, Order, Family, Genus, and Species.

A good trick to remembering the order of these ranks is with the pneumonic "Don't Keep Pushing Cream On Fungi Growing Spores."

	Garden Giant	Turkey Tail	Candle Snuff	Koji	Garden *Glomus*
Domain	Eukaryota	Eukaryota	Eukaryota	Eukaryota	Eukaryota
Kingdom	Mycetae	Mycetae	Mycetae	Mycetae	Mycetae
Phylla	Basidiomycota	Basidiomycota	Ascomycota	Ascomycota	Glomeromycota
Class	Agaricomycetes	Agaricomycetes	Sordiariomycetes	Eurotiomycetes	Glomeromycetes
Order	Agaricales	Polyporales	Xylariales	Eurotiales	Glomerales
Family	Strophariaceae	Polyporaceae	Xylariaceae	Trichocomaceae	Glomeraceae
Genus	*Stropharia*	*Trametes*	*Xylaria*	*Aspergillus*	*Glomus*
Species	*rugosoannulata*	*versicolor*	*hypoxylon*	*oryzae*	*intraradices*

Example taxonomies of several common fungi. Differences between taxonomic ranks reflect a speciation event.

Along with helping track the known species on Earth, taxonomies can also be used to approximate the evolutionary history of a species. Each of the eight divisions in a taxonomic classification reflects a major evolutionary change, or "speciation event," that led to a novel lineage of organisms. When these histories and relationships are mapped into a cohesive whole, they form a branching network known as the Tree of Life or, as discussed in Chapter 3, what may be more accurately termed the Mycelium of Life (MOL). Therefore, the name of a fungus can be used to guess the history of its ancestors and the knowledge it has inherited along the way, much like a human's family tree.

The combination of an organism's Genus and Species title forms its universally accepted "Latin name." This *binomial* is used to denote a given species, defined as a group of living organisms that share similar physical features and are capable of interbreeding. It is recommended up front to get comfortable with using Latin names to describe fungi as, unlike a fungus' common name that can differ between languages and regions of the world, the current Latin name of a species does not change as one travels. Also, many species do not have common names, leaving the Latin name as the only option. As with getting to know any new friend, remembering the names and relationships of fungi can take some time. Even pronouncing their names can be a bit of a tongue twister at first. But don't worry, no one even truly knows how the Romans pronounced Latin. Plus, the fungus probably doesn't care: it didn't even choose its name to begin with.

Despite the commonality of the Linnaean system, it is not without flaws. For example, it cannot fully account for the subtle differences between fungal species. Many fungi exhibit a wide variety of forms and colorations in some features, making it difficult to delineate where to draw a line between one species and the next. For some mushroom species, this line is so blurry that closely related species are simply lumped together under the blanket terms of "complex" or "group" until they can be sorted out. Many fungi completely defy the concept of a species, making their classification under the Linnaean system difficult, if not impossible.[4] As fungal taxonomist R. W. G. Dennis once said, "[Taxonomy is] the art of classifying organisms: not a science but an art, for its triumphs result not from experiment but from disciplined imagination guided by intuition."[5]

Further, fungal taxonomy is currently in a major state of revision as recent research into fungal genetics is presenting major contradictions to presumed fungal lineages. Species long considered closely related due to their similar morphologies are now said to be distant relatives. The result is not only significant confusion amongst professional and amateur mycologists, but also heated debates amongst the many devout mycophiles invested in the revision process.

Problems such as these have led ecologists in recent decades to suggest that the current sophistication of biology requires the replacement of a lineage-based naming system with one that describes the current relationships that a given species holds within its environment.[6] Such a system would acknowledge lichens, which are currently not even on the MOL due to lichens being a symbiosis and not a singular organism. Such a system would also help any mycologist understand the intimate connections that a fungus forms in its environment simply through the name one uses to identify it. To reclaim the language used to describe Nature is, in many ways, a chance to speak the language of connectivity that fungi express.

The Fungal Features and Forms

Fungi come in all shapes and sizes—from tiny, single celled creatures, to giant masses that span hectares. In general, all host the following combination of traits:

Eating Habit

To obtain their energy, fungi do not photosynthesize or engulf food like animals. Fungi absorb nutrients through their tissue, mostly in the form of minerals, small sugars, amino acids, and peptides. To obtain these nutrients, many fungi release various acids and enzymes to externally digest substances in their environment.

Energy Storage

Fungi primarily store excess nutrients in the form of sugar alcohols, such as mannitol; as trehalose, a glucose disaccharide, also known as mycose; and/or as glycogen, a substance also used for storage in animals.

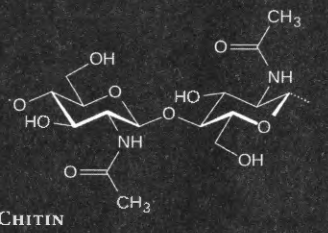
Nuclear Status

Unlike prokaryotic bacteria, which do not contain their DNA inside of a discrete compartment, fungi are eukaryotes that hold their DNA inside of a well-defined nucleus. Each fungal cell may be uni- or multi-nucleate, while the fruit body of a mushroom-forming fungus may be filled with the same type of nuclei (homokaryotic) or with mixed nuclei (heterokaryotic). The nuclei of some fungi (such as Basidiomycete mushrooms) can be haploid for their entire vegetative state, a feature not shared by plants, animals, slime molds, or protists.

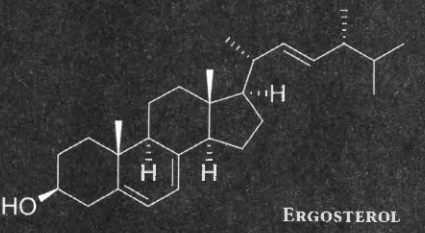
Cell Membrane and Wall Structure

Unlike animals, the primary sterol in the fungal cell membrane is not cholesterol, but ergosterol. Beyond their cell membrane, fungi also have a rigid cell wall. However, unlike plants, this cell wall is not reinforced with cellulose but by microfibrils of chitin, a glucosamine polymer that also comprises the bulk of insect exoskeletons and crustacean shells. These chitin microfibrils are connected by highly branched glucan sugars, which comprise 80-90% of the entire cell wall. On the exterior of the cell wall is a matrix of gel-like or crystalline material. Fungal cells can be represented empirically as $C_{10}H_{17}O_6N$.

Fungi are found in a variety of forms. Approximately 1% of all known fungi (about 600 species in 60 genera) are yeasts: single celled organisms that reproduce by self-cloning, or "budding." Others are microscopic, aquatic, and/or parasitic species that reproduce by means of tiny spore-bearing structures. The vast majority of fungi form mycelium, a distributed network of tissue through which nutrients, cytoplasm, and genetic information can travel. These mycelium-forming, or "filamentous," fungi may or may not form mushrooms. For this book, the term "mushroom" denotes a three-dimensional fruit body of a fungus that can be easily described and touched.



Chitin



Ergosterol

The Fungal Phyla

The first words one must learn in the language of mycology are the names of the fungal phyla and the descriptors of their unique qualities. Queendom Fungi is divided into seven phyla: the Chytridiomycota, Blastocladiomycota, Neocallimastigomycota, Microsporidia, Glomeromycota, Ascomycota, and Basidiomycota. The first five of these groups contain single-celled and/or cryptic, soil-dwelling species that are not easy to observe or identify without the aid of a microscope. The latter two also contain micro fungi, such as molds and yeasts, but are unique in their ability to form mushrooms. These two groups are also placed in the subkingdom Dikarya as they host species that contain two distinct types of nuceli for a significant portion of their life cycle.

Due to a recent revision of the entire Queendom, the traditional phylum of the Zygomycota is no longer recognized.[7] As such, the various subphyla that it once contained are placed together under the "container" of the term Zygomycota. Hopefully, these groups will be given a proper position in coming years. Many older textbooks place fungi without a sexual stage (sometimes poorly referred to as *Fungi Imperfecti*) into the phylum Deuteromycetes, a grouping that is no longer recognized. Several genera of "basal" fungi are not currently placed in any larger grouping. These include *Basidiobolus*, *Caulochytrium*, *Olpidium*, and *Rozella*.

Species across phyla may reproduce sexually (i.e. by sharing and recombining genetic information with genetically compatible "mates"), and/or parasexually (i.e. by fusing nuclei that later go through de-diploidization), and/or asexually (meaning the DNA of their offspring is identical to that of the parent fungus—the fungus essentially buds off a piece of itself that can easily travel and start regrowing elsewhere). The example life cycles presented below for each phyla are considered typical, however many variations exist within each group.

Chytridomycota (*706 species in 105 genera*)
Neocallimastigomycota (*20 species in 6 genera*)
Blastocladiomycota (*179 species in 14 genera*)

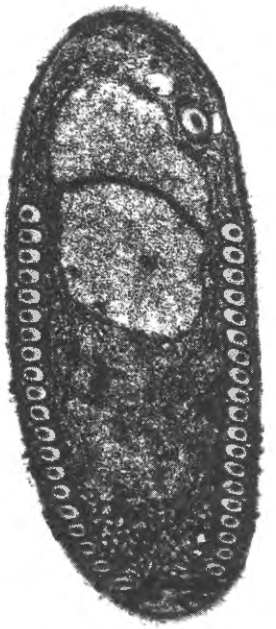
Chytrids

These three closely related phyla share many similarities. They are single-celled and most have a unique tail, or *flagella*, which enables them to move through their aquatic environments. Chytrids are about the same size and shape of sperm, though their tail is about half as long as those of these animal gametes. The oldest Chytrid fossils date from the Devonian period (ca. 400 million years ago) and share similarities to species in the modern genus *Allomyces*.

Chytrids are primarily decomposers of tiny pieces of organic debris, such as pollen or insect chitin. Some also parasitize plants or bacteria. Species in various genera, such as the *Neocallimastix*, *Piromyces*, *Orpinomyces*, *Anaeromyces*, *Caecomyces*, and *Cyllamyces*, are found in the guts of large animals where they help the animal digest its food. The lifecycle of most Chytrids are not well understood and can differ widely between species.

Microsporidia (*ca. 1,300 species in 170 genera*)

These single-celled fungi were long thought to be a type of protozoa until it was recently determined that they are actually simple fungi that lack mitochondria. Most Microsporidia are obligate parasites of insects, crustaceans, fish, humans, and other animals. Some can even be hyperparasites that parasitize the parasites of other animals. For example, Microsporidia in the genus *Nosema* can infect flatworms that, in turn, infect mollusks.



The spore of Fibrillanosema, *a species in the Microsporidia.*

Zygomycota

A mixed bag of cosmopolitan micro fungi, the Zygomycota is no longer recognized as a true fungal phylum. As such, the following four subphyla of the old Zygomycota are all *incertae sedis* ("of uncertain position") in the Queendom:

- **Mucoromycotina** (*325 species in 61 genera*)
- **Kickxellomycotina** (*94 species in 22 genera*)
- **Zoopagomycotina** (*212 species in 20 genera*)
- **Entomophthoromycotina** (*ca. 250 species*)

Glomeromycota (*169 morphospecies in 10 genera*)

Arbuscular mycorrhizal fungi, AMF, or AM

The Glomeromycota are among the most ancient terrestrial fungi, with their oldest fossils dating to over 450 million years ago. They are globally distributed, soil-dwelling, mycelium-forming, non-mushroom-forming species of Arctic, temperate, and tropical regions. With few defining features, these fungi are often only identified to genus using their spore development strategy and spore wall structure. Unlike most other fungi, spores of the Glomeromycota are often large enough to see with the naked eye, though microscopes are needed for accurate identification. These spores may be formed singularly, in clusters, or aggregated in structures known as *sporocarps*; all are produced asexually. Depending on the age, health, and climate of their habitat, these spores may be produced in low or abundant numbers. Woodlands can host 1–5 spores per gram of soil and agricultural sites may have 9–89 spores per gram of soil. Sand dunes may only host four spores per cubic centimeter.[8] Some of the best-studied genera are *Gigaspora, Acculospora, Sclerocystis,* and *Glomus. Glomus* is the largest genus, hosting more than 70 morphospecies.

All species in the Glomeromycota form a symbiotic relationship with plant roots. Their mycelium wraps around and penetrates root tips to form structures known as *arbuscules* inside of the root's cells. Using these arbuscules as an interface, nutrients are exchanged between both species. The fungus provides the plant with water and nutrients that it draws in through its mycelial network and, in exchange, the plant provides the fungus with photosynthesized sugars in the form of glucose and fructose. This relationship, known as a *mycorrhizal symbiosis*, is mutually beneficial to both partners, with the glomeromycotan fungi being completely dependent on the plant for its survival. This relationship is formed with approximately 85–90% of all plant species and has vast ecological significance.

A Typical Life Cycle of Glomeromycotan Fungi

1. Spores germinate near a plant root and enter the root in response to root exudates.
2. Hyphae grow through the root's cell layers, with the proliferation of intercellular hyphae being controlled by the plant.[9] The hyphae form structures in the root cortex known as *appressoria*, which are able to penetrate the root cells' protective wall.
3. The plant cell wall then invaginates and grows around the branching hypha, which is now referred to as an *arbuscule*. The fungus does not penetrate the plasma membrane of the root's cell but the root cells are significantly modified to accommodate the arbuscule. A fluid medium is created between the two organisms and through it nutrients are exchanged. Arbuscules take 2–3 days to form and last for around 4–15 days, after which time they break down and the plant cell returns to normal. Adequate explanations for the short lifespan of arbuscules have not been offered.[10] The arbuscule was long thought to be the sole site of nutrient exchange, however it is also possible that intercellular hyphae and/or coils could also absorb nutrients from the plant.
4. Many AM fungi (except those in the family Gigasporaceae) also produce spherical or oval-shaped *vesicles* between or within the root's outer cells. These are thought to serve as a form of lipid (fat) storage and are formed when a hyphal tip swells to

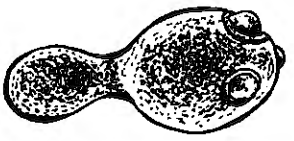
over 100 μm in diameter.

5. The total mycorrhizal structure now formed is comprised of three main parts: the root, the fungal structures between and within cells, and the mycelium that extends into the soil as it surveys, connects, and learns about its environment.[11]

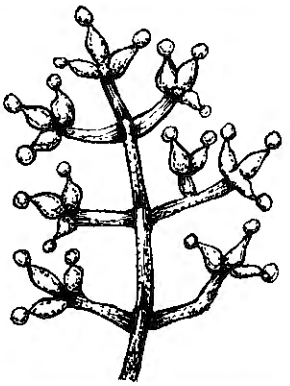
A unique and important product of glomeromycotan fungi is *glomalin*, a sticky protein exuded on the surface of their mycelium. As these fungi move through the soil, this protein "gloms" soil particles together. And as these clusters build in number, porosity and structure are created in the soil matrix. Glomalin thereby makes the soil fluffy yet stable, a quality that enables water and oxygen to easily penetrate the soil and allows beneficial oxygen breathing microbes to survive at greater depths. At the same time, the binding action of glomalin, hyphae, and plant roots reduces erosion and topsoil loss. Glomalin is directly responsible for turning dirt into soil, creating the "tilth" in soils that enables roots, microbes, and worms to move and thrive, and ultimately increasing diversity, redundancy, and resilience in the soil matrix. Only the Glomeromycota produce glomalin, placing them as central designers in the creation of subterranean and aboveground ecologies.

Since its discovery in 1996 by Sarah Wright, the chemical structure of glomalin has remained poorly understood. It is a nitrogen-linked glycoprotein composed of 3–5% nitrogen, 36–59% carbon, 4–6% hydrogen, 33–49% oxygen, 0.03–0.1% phosphorus, and 0.8–8.8% iron. The iron component may be responsible for the reddish color of glomalin extracts as well as its strong antimicrobial properties, thermal stability, and soil stabilization traits. It is hydrophobic, insoluble, and, being very resistant to decomposition, can persist in the soil for at least 10–50 years.

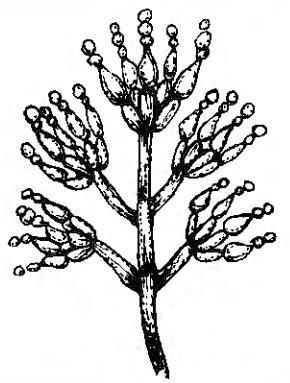
Combined with the antiquity of the Glomeromycota, these properties suggest glomalin may be more abundant than humic acids in many soils and may even contain one-third of all sequestered carbon in the habitats where Glomeromycota are present.[12] With such important influences on the soil environment, whole plant communities, and the animal diversity of an ecosystem, the Glomeromycota may be the most ecologically significant of all fungal phyla.



Yeasts tend to reproduce in part by budding.



A Trichoderma *conidiophore.*



A Penicillium *conidiophore.*

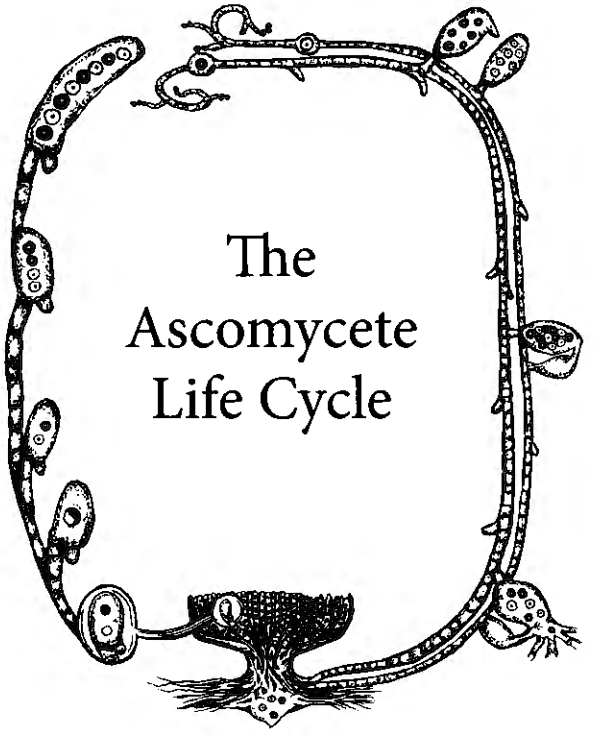
Ascomycota (*64,163 species in 6,355 genera*)

Ascomycetes, ascos

Hosting approximately 75% of the described fungal species, the Ascomycota is the largest phylum in the Queendom. Almost all of the fungi that form a lichen, endophytic symbiosis, or ericoid mycorrhiza (relationships detailed in coming chapters) are Ascomycetes, as are those applied in the production of beer, bread, many industrial enzymes, and a number of culturally important fermented foods. Many form mycorrhizal relationships with plants, while a small number are notable pathogens (e.g. Dutch elm disease, chestnut blight, ergot, ringworm, and powdery mildews). Some of the best-studied genera in this phylum are non-mushroom-forming. These include *Penicillium, Trichoderma, Aspergillus, Saccharomycetes,* and *Candida*. The yeast *Saccharomycetes cerevisiae* was the first eukaryote to have its entire genome sequenced (it has 12,067,266 base pairs, 16 chromosomes, and 6,275 genes).[13] The mycelium-forming species *Neurospora crassa* has been heavily studied as a model organism for genetic recombination research. Mushroom-forming genera include *Morchella, Aleuria, Peziza,* and *Xylaria. Terfezia* and *Tuber* host many of the prized edible truffles.

A small percentage of Ascomycetes are yeasts; the rest form mycelium. Many Ascomycete molds only reproduce asexually. The mycelial networks of these fungi develop from a single, genetically complete spore and within hours or days begin producing discrete, single-celled clones (spores) that are durable enough to travel and establish elsewhere. These *conidia,* or *conidiospores,* form on a structure known as a *conidiophores*. Both features vary widely in size and shape but are generally unique enough per genera or species to be used for identification.

The sexually reproducing Ascomycetes—all in the order Pezizales—constitute 90% of the phylum. Whether mycorrhizal, parasitic, or saprotrophic, a typical life cycle for these fungi is as follows:



The Ascomycete Life Cycle

1. A haploid spore lands in a suitable environment and germinates, sending out a thread of tissue, known as a *hypha* (pl. *hyphae*), that is one cell thick. As the hypha grows, it braches, forming a network of *primary mycelium* that is *monokaryotic* (i.e. it contains one type of nucleus).
2. Two genetically compatible mycelial networks, each produced by a different spore, encounter each other and become "partners." Mated, the two travel together, cohabitating alongside each other, but do not fuse together.
3. Once the partnered network becomes large enough, the two mycelia weave together, forming a *fruit body*.
4. Once the fruit body is mature, the two mycelia begin spore production. One of the partners forms a single-celled sexual structure known as the "female" *ascogonium*, while the other forms a "male" *antheridium*.
5. The ascogonium sends out a *trichogyne peg*, or "fertilization tube," to bridge the two cells together, enabling the antheridium to pass nuclei into the ascogonium.
6. The ascogonium folds over, forming a *crozier hook* in which the two types of nuclei fuse and divide through the processes of meiosis and mitosis, resulting in several distinct, offspring nuclei.
7. The ascogonium morphs into an *ascus* (pl. *acsi*) filled with mature *ascospores*. Typically, each ascus contains eight spores, though some species produce thousands per ascus. Between asci are sterile hyphal tips known as *paraphyses*. This layer of fertile tissue where spores develop and disperse is known as the *hymenium*.
8. Pressure builds in the asci until they ultimately explode, launching their spores into the world. This often looks like ping pong balls being shot out of the top of a condom.
9. Many of these fungi also have an alternate, asexual component to their life cycle. These fungi can thus replicate their already existing and successful genetics via self-cloning, mate and produce novel offspring sexually, or perform both processes, depending on the species and environmental conditions.

The hymenium of Ascomycete mushrooms is typically found in one of the following structures:

- **Apothecium:** Fleshy, stalkless, cup- or saucer-shaped fruit bodies comprised of three parts: the *hymenium* (on an upper concave surface), the *hypothecium*, and the *excipulum*. A Morel mushroom is essentially a mass of multiple apothecia fused together atop a stalk, while the apothecia of the lichen *Letharia columbiana* form as small clusters.
- **Perithecium:** Flask-shaped structures that look like an almost-closed apothecium. Spores are released through a small opening known as an *ostiole*. Perithecia are found in many genera, including *Xylaria*, *Nectria*, as well as in many lichen species.
- **Cleistothecium:** Globose, closed fruit bodies with no special opening to the outside. The ascomatal wall is called the *peridium* and its asci are often scattered, globular, and tend to liquify in age. Cleistothecia are found mostly in fungi that do not rely on the wind for spore dispersal, such as the truffles in the genus *Tuber*.
- **Gymnothecium:** These structures are similar to cleistothecium but have a more loosely woven peridium.

Basidiomycota (*31,515 species in 1,589 genera*)

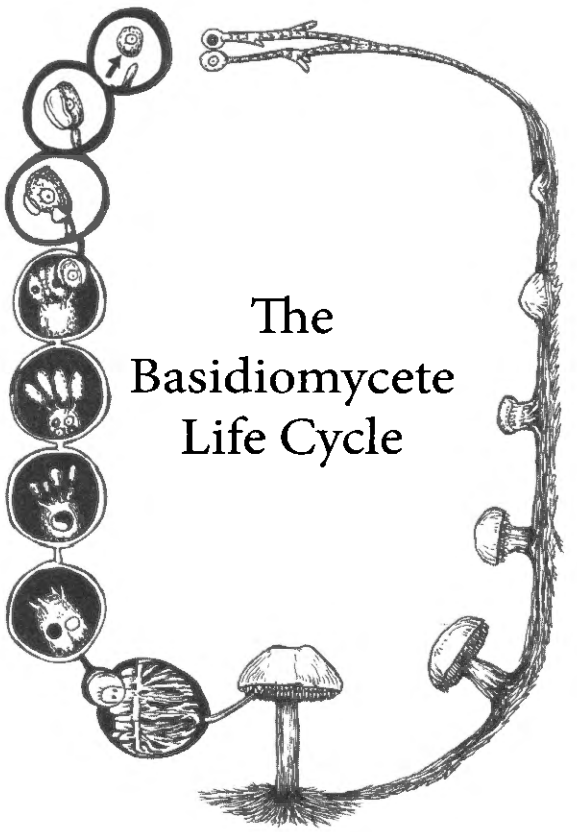
Basidiomycetes, basidios

With their ability to produce complex fruit bodies, the Basidiomycota and Ascomyota are considered the most highly evolved fungi. Basidios include the majority of edible, medicinal, cultivated, wild harvested, and remediative mushrooms. Some are yeasts, a few form lichen associations, some are pathogenic to humans, and a good number form rust and smut blights on plants (relationships detailed in Chapter 2). The following is a typical life cycle of a mushroom-forming Basidiomycete:

1. A haploid spore lands in a suitable habitat, germinates, and forms monokaryotic primary mycelium.
2. The mycelium branches out in three dimensions, gathering nutrients and water, while also seeking a compatible mycelial network produced by another spore. As primary mycelium, the fungus can grow and survive on its own for a long time; it just won't be able to produce mushrooms without a "mate."
3. Two compatible mycelial networks encounter each other and fuse together in a process known as *anastomosis*.
4. Now fused, the two primary mycelia swap their intercellular fluids and nuceli, forming a network of *secondary mycelium* that is *dikaryotic* (i.e. containing two sets of nuclei). This dikaryotic state is unique to fungi.
5. The mycelium extends at the tip of each hypha. As new segments are added to the tip, *clamp connections* form between segments to help coordinate the replication of nuclei. At room temperature, most Basidiomycetes form a clamp connection every 60 minutes. Simultaneous nuclear division occurs about every 2–3 minutes.
6. The dikaryotic mycelium continues to grow until it runs out of food or space or if other environmental signals trigger the formation of a mushroom (e.g. a change in temperature or humidity).
7. Some of the mycelium aggregates into a *hyphal knot* that quickly develops into a *primordium*.
8. Primordia mature into fully formed mushrooms.
9. Across the mushroom's hymenium, hyphal tips develop into club-shaped structures known as *basidium* (pl. *basidia*), from which the phylum gets its name. The hymenium typically forms on the surface of gills, teeth, or on the inside of small tubes.
10. Inside the basidia, the two nuclei of the dikaryotic mycelium fuse together for the first time and quickly undergo meiosis and mitosis, producing several new nuclei.
11. On top of the basidium small peg-like appendages called *sterigmata* develop. *Basidiospores* form on the sterigmata and take up the nuclei in the basidia. Typically there

are four basidiospores produced per basidium, but variations exist. For example, *Agaricus bisporus* has two spores per basidium and *Phallus impudicus* produces nine each.

12. As a spore matures, mannitol and other sugars are released from the spore's bottom and side. These sugar spots attract moisture in the air, producing two water droplets on the spore. Once large enough, these drops touch and rapidly move up the spore, shifting the spore's center of gravity and launching it off the sterigmata with incredible force. In one-millionth of a second the spore is ejected with a velocity of one meter per second, comparable to a human moving at 500 times the speed of sound.[14] This spore dispersal strategy is known as *ballistospory* and it is unique to the Basidiomycota. Ballistospory's requirement for moisture may explain why mushroom flesh is notably cool: lower temperatures can help increase condensation on the spores.[15]
13. Due to the tiny mass of the spore and the surface drag that results from its movement through the air, the spore ceases to move after just a few milliseconds and goes into a free fall. With incredible precision, the size, shape, development, and release of spores are all calculated to ensure that the each spore is able to fall and disperse unimpeded by other spores.



Oomycota

The Oomycota (ca. 800–1,000 species) are the slime and water molds that, though somewhat fungal in appearance, are more closely related to diatoms and brown algae than fungi. Many are microscopic, while others form large amoeba- or fungus-like structures that can be easily observed and identified. Many feed on dead fungi. Mycologists historically studied Oomycetes, but they now loom in the land of understudied organisms.

The Finer Points of the Fungi

With the primary descriptors of fungi covered, we now move on to some of the more striking, inexplicable, and unique aspects of their biology. We begin where everything begins, with a spore.

Spore Liberation

> *The spore is everything that the fungus represents. Whole, undivided, sovereign, it is a world unto itself, a vessel of autonomy that, though seemingly just the same as countless others, holds within itself the untold legacies of bygone ancestors and of fungal webs yet to come. The spore is the beginning and the end of fungal evolution. It is the rest between heartbeats in the network, the silence between notes that fruiting bodies sing, and the moment before the soil inhales. Resilient, inspired, and ancient, spores are the still point from which storms arise to spawn whole communities and whole ecologies. She who counts the spores of the world is the one who measures the world itself. Fungi as spores, spore as fungus, fungi as life. One and the same, perfect and complete.*

Unlike cells found in the mycelium and fruiting bodies of mushrooms, the spore is unique in its dedicated purpose to travel and evolve. But, being limited in mobility, the spore is at the mercy of the forces around it. Thus, some spores move though the world with the help of other organisms. Truffles and the Glomeromycota largely rely on small insects and animals to eat and redeposit their spores in further environs—intertwined ecologies that bridge fungus with animals and the plants they both inhabit. Other spores may grow in acutely defined structures that rely on the precise splash of a raindrop to carry them away. Some are ejected forcibly. The spores of dung-inhabiting (coprophilic) *Pilobolus* species have the greatest self-dispersal range. These single cells are launched from their substrate with a force of over 20,000 Gs to land an impressive 2 meters away.

Most fungi, however, rely on the wind to carry their spores. In the middle of a forest where winds are low, spores often travel less than three feet from their parent mushroom. But where winds are particularly strong and turbulent—such as on the edge of a forest—spores are free to roam. Here, some spores may be lifted into the upper layers of the atmosphere and carried on air currents across oceans, just as the coffee rust fungus (*Hemileia vastatrix*) may have done in its move from Africa to South America.[16] As spores fill the sky, the same attractants that create the water droplets during ballistopory may draw water to condense on atmospheric spores, making them important "seeds" in the formation of rainclouds around the world.[17] Rains fall, mushrooms form, and spores ascend. Through the actions of fungi, the cycles of life begin anew.

Some species spread an incredible number of spores. A single Artist's Conk may release up to 30,000,000,000 spores a day, or 5 trillion spores over the course of a 6-month growing cycle. A single 2-foot wide Giant Puffball (*Calvatia gigantea*) may contain as many as 7 trillion spores. Within just a few days of germinating, a 2.5-centimeter wide mycelial network of *Penicillium* can produce over 400,000,000 conidiospores. The annual weight of basidiospores released around the world may equal 17 megatons, or as much as 100,000 blue whales. Spores fill our lungs with every breath, with around 500 spores contained in each cubic meter of air in the summer months. To aid in dispersal, spores may be spikey, bumpy, netted, globular, or long and skinny. Others are perfect spheres. They also come in a wide array of colors, an aesthetic feature not explainable by mycologists.

To germinate and survive, spores must land in a supportive environment that can provide protection, water, and food. Spores cannot survive without being nurtured by their habitat. Each falls alone, vulnerable to the whims of weather and the luck of their landing. Indeed, most spores do not germinate and instead add to the food web as nourishment for springtails, slugs, or amoeba.

Spores that evade such predators but land under imperfect conditions may simply lie dormant until the proper conditions arise. Some spores can survive for an indeterminate number of years, a fact underlying theories of fungal origins on another world. Indeed, viable spores of *Cladosporium cladosporioides* and other fungi have been obtained from 4,500-year-old glacial ice cores, a testament to their ability to survive the trials of space and time.[18]

The most unusual and resilient spores are undoubtedly those produced by the Glomeromycota, the soil dwelling, mycorrhizal fungi of ancient origins. At 40–800 μm in diameter, these spores are 2–40 times larger than the typical fungal spore's 5–20 μm girth. However, this massive size is not some holdover of a bygone survival strategy. It is needed by the fungus to accommodate the incredible genetic diversity packed into each spore. Typically, spores (and cells in general) only contain one nucleus, which itself contains the DNA used to reproduce the parent fungus or organism. Glomeromycotan fungi, on the other hand, each contain an incredible suite of 800–35,000 genetically distinct nuclei in each of their spores.[19] Many of these nuclei can be from other microorganisms, including fungi of other phyla.[20]

This remarkable genetic collage is the reason why Glomeromycotan fungi can only be identified by their visible spore characteristics and hyphal structures[21]: such a mixed bag defies accurate DNA sequencing, leaving mycologists with no molecular species concept for glomeromycotan fungi. Countless questions come from this singular phenomenon. As each spore germinates, which nucleus takes the reigns? Which guides the growth of the fungus and the many roles it plays as a mycorrhizal partner shared by countless plants? Is there a primary nucleus or do many (all?) act in concert? How did these nuclei accumulate and when? Does their diversity change over time? If so, how, where, and why are these nuclei spread?

The simplest answer to these questions would be that this genetic warehousing provides these fungi with an array of genetic "options" from which to draw from in response to environmental factors (an act known as *epigenetic expression*). However, the nuclear diversity of the Glomeromycota provides for a wealth of genetic reserves that is more advanced than essentially all other eukaryotic organisms. Seems a bit excessive for such an old fungus. However, this genetic resilience does add an evolutionary advantage that may account for the fact that the Glomeromycota have hardly changed their form over the 450 million years of their recorded existence.

In one study, such epigenetic changes were observed in a glomeromycotan fungus over the course of only a few months. Here, researchers inoculated a potted plant with a single spore of *Glomus irregulare*, grew the fungus through its life cycle until it produced spores, and then collected a single spore. This spore was then used to repeat the growing process. A third round followed and replicates were made for each cycle.

As *G. irregulare* is asexual, the result of these few growing cycles would be assumed to have produced little, if any, change in the spore's characteristics. The spores harvested in the final pot should have looked and acted just like the original spore. But, when the study was concluded and the data was assessed, it was clear that each generation had produced significant changes in the appearance and actions of the fungus.[22] Such results reflect the common observation that the DNA of Glomeromycota collected in the wild often does not match the sequences of known pot-cultured species.[23] To quote the paper directly,

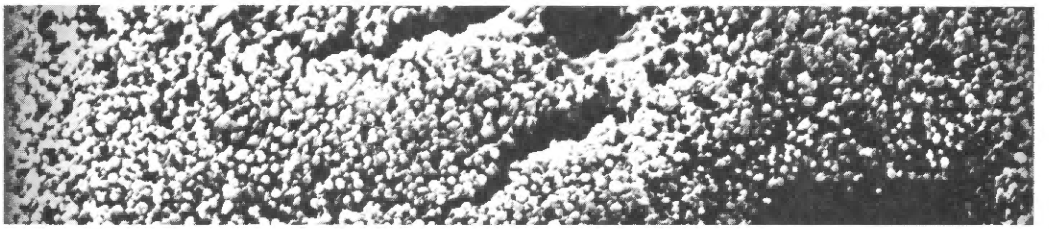
> *"Our results have important consequences that show that, depending on the cultivation method, the genetic make-up of the fungus can be altered significantly."*

Adding to these adaptive traits is the fact that, unlike other filamentous fungi, the mycelium of different species in the Glomeromycota can fuse together and exchange their hundreds of nuclei. This intraspecies breeding act has been shown to occur between various *Glomus* species, which can share their mycelial contents, bidirectionally, at a flow rate of two millimeters per second.[24] During this exchange, the DNA of both species may recombine,[25] forming hybrid nuclei with the combined genetic intelligence of the parent nuclei. These or similar forms of "cleaning up the genome" may be what has enabled these fungi to persist in a relatively stable form for so long.[26] These profound genetic capacities are unlike any other adaptive strategy found amongst eukaryotic organisms and, as such, deserve significant attention for their numerous ecological implications.

Currently, there are around 169 "morphospecies" in the Glomeromycota. But considering the above traits, this number may be a severe underestimate of the true diversity in the phylum.[27] And that's if one considers the Glomeromycota to even be true species. Many researchers suggest that these fungi defy the Biological Species Concept and should instead be regarded as "form species,"[28] or what is known more colloquially as a shapeshifter. Other mycologists suggest that the Glomero-

mycota are fundamentally different from other fungi, or even other eukaryotes.[29] In other words, these organisms could be considered a completely unique branch on the MOL, one that pervades all soil systems and connects the majority of the world's plants into a distributed network of shared nutrients and nuclei.

The Glomermycota are not just a group of ancient species that has survived the trials of extinction and evolution. From season to season and spore to spore, they have spread across time and space to build the ecologies that define the world. They are amongst the eldest ancestors of the terrestrial Earth and the perpetual stewards of the world's ecosystems. Within their mycelial networks and spores of life these fungi hold the memories of prehistory. They are the knowledge keepers of the soil and the designers of the wild. Endlessly branching across the planet, the hidden networks of the Glomeromycota carry the Fungal Queendom's power to support and enhance all of life through the connections they weave into the innumerable messages of their hidden mycelium.



The Crossover

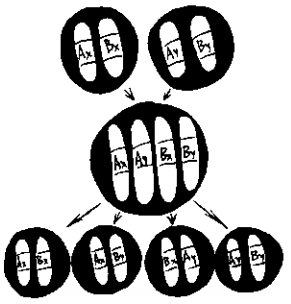
With a staggeringly wide range of mating habits, fungi are by far the most sexually diverse of all organisms.[30] Many species deviate significantly from the generic life cycles described above, leaving fungal sex poorly understood in general. Others have multiple reproductive options, as noted with the Ascomycetes. Some form both a sexually reproductive structure, known as a *teleomorph*, as well as an asexual form, or *anamorph*. To further complicate the issue, the same species can have two different names depending on which of these states it is in. This dual naming practice was common in mycology until 2013 when the "one fungus, one name" rule was set in place. Some species still retain this dual name nature, a common point of confusion for budding mycologists.

The greatest research into fungal sex has been conducted with mushroom-forming Basidiomycetes. For these fungi, the two primary mycelial networks that fuse to become a mushroom must be genetically compatible. But lacking sexual organs, this compatibility is not determined by physical features of the hyphae. Rather, it is through the exchange of chemical signals, or mycopheromones, that a primary mycelial network is able to locate another network that is of the same species but with DNA that is sufficiently dissimilar to avoid the negative effects of "inbreeding."

For most eukaryotes, the DNA inside of every nucleus is not grouped in one cohesive mass, but distributed between many *chromosomes* of various sizes. Each chromosome can further be defined as an assemblage of many short DNA segments known as *genes*, which also vary in size. In Basidiomycetes, there are two genes that determine mating, each of which are located on separate chromosomes at known positions: locus A and locus B.

In order for two hyphae to mate, the gene sequence at each of these loci must be different. Most species have at least two possible sequence options, or *alleles*, for each locus, though some have many more. To create genetic variation in each spore, these alleles get shuffled around during the meiosis that occurs in the basidia just before spore development. Spores that have a large array of allele diversity have a greater ability to mate with other spores, effectively increasing the adaptive capacity of the fungus by providing a spore with more "options" wherever it lands. The Split Gill Fungus has more than 300 alleles at the A locus and more than 90 at the B locus, a diversity that provides for 23,328 different combinations of A and B alleles, or over 23,000 different mating types! Each of these spores is compatible with over 98% of other Split Gill primary mycelia in the world,[31] a breeding capacity that underlies the global distribution of this common mushroom.

During the genetic rearrangement that occurs during spore development, the sexual alleles are



For many sexual fungi, loci with differing alleles are required for mating and the production of offspring spores.

not the only genes that change. Similar to how genetics get rearranged in the development of each animal sperm, each sexually produced spore is a unique expression of its parent mushroom and also quite different than the majority of its sibling. This creation of genetic diversity, whether in fungi, animals, or other organisms, is what enables evolution to occur and for related humans to look and act differently. However, in the fungi, the potential for rapid adaptation is vastly increased due to the high number of spores that each fruit body produces. In essence, by producing millions or billions of spores, sexual fungi provide themselves with an incredibly resilient means for surviving in any new environment or substrate. This is one of the reasons why fungi have been able to spread so successfully across the world's various habitats.

From the Center to the Periphery

> *The mycelium that fills the world is the fungus that we do not see. Sunken beneath the recesses and pervading all niches, mycelium is the silent and hidden connector, cleanser, and healer of the world. It is the maker of potent medicines, the eldest architect of forest and desert, and the destroyer of concrete and wood. From the mycelium we have come, and to its web we shall return to be embraced, dissolved, and recomposed through the endless turning of life's cycles.*

A spore germinates and the world begins. Thin and singular, the life of the fungus erupts as a filament of tissue: the hypha. With its simple form and curious, wandering nature, the hyphal bud is easy to overlook—merely another microbe among the millions. Yet each holds within itself the life of countless mycelial networks to come. To overlook the hypha in its singular is to overlook the unlimited potential of every child, each being shaped by the guidance of its environment.

Only one cell wide, the hypha spans a mere 10 μm, or 1/100 of a millimeter, as it moves through its *substrate*, which is simultaneously the fungus' habitat and source of nourishment. This small size is efficient for the lifestyle of the fungus as its high surface area allows for maximum exposure to the environment, while minimizing any crowding effect that the fungus may have on other species. The mycelium is as space-efficient as the human circulatory system, the latter of which only takes up 5% of the human body yet is able to place a capillary no more than three or four cells apart.[32] Likewise, more than eight miles of mycelium may fill each cubic inch of soil, yet fungi only comprise 5–10% of the entire mass.

Hyphal growth is an act of temporal and spatial extension. As the mycelium moves forward, it grows apically (i.e. from its tip or apex). As the tip is added to, the hyphal sidewalls are cemented in place. Once constructed, these walls do not lengthen.

During this process, the fungus does not create a chain of discrete, walled-off cells, as one might expect. Rather, as the hypha extends, it constantly adds to the existing tissue, forming a single, interconnected, and massive cell. Much like a wild river system, mycelium flows as an open circulatory network of shared waters, nutrients, and information.

Some fungi do form cross walls, or *septa* (pl. *septae*), in their hyphae, giving each thread the appearance of being comprised of individual cells. However, these septae almost always have a large opening, or pore, in their center that allows for the free movement of intermycelial contents. All glomeromycotan fungi lack these cross walls entirely (they are *aseptate*), giving them the appearance of non-constricted and well-connected arteries. These fungi also form mycorrhizae with 90% of plants and frequently share nutrients and fluids between dozens of plant partners connected through a common mycelial network. In essence, these fungi *are* the circulatory system of the world.

As the hypha grows through its environment it seeks out water and food. Water is absorbed through the surface of the hypha while nutrients are obtained by external digestion. These digestive enzymes are exuded primarily from the hyphal tip and their composition varies in response to a given substrate. Different fungi eat different things. Some are rather picky eaters that have adapted to fill a specific niche, others don't discriminate and will eat almost anything in their path.

Regardless of their substrate, all mycelia rely heavily on their digestive enzymes to transform substrates into compounds that are small enough to absorb. Some of these enzymes are soluble and

can travel easily into the external environment. Others stay bound to the surface of the mycelium or to the substrate that they touch, helping the fungus ensure that released nutrients are not eaten by other microbes.[33]

To metabolize their substrate, fungi require oxygen, which is primarily taken in by diffusion. After the oxygen has gone through respiration in the hypha, it is expelled as $C0_2$ that is later taken up by plant tissues above ground. And as the fungus continues to travel onward, the byproducts of its digestion are left to permeate the environment, providing food for other organisms.

The digestive enzymes of fungi, like all enzymes, are types of proteins used to start and/or speed up chemical reactions within or outside of cells. Enzyme production is a complex, yet central process to all of life. Enzymes are responsible for the vast majority of the work that occurs within cells. Without enzymes, life would not be able to occur. Like all proteins, enzymes are built, folded, and moved around the cell through various stages, generally being first formed in an organelle known at the endoplasmic reticulum (ER) and then moved to another organelle, the Golgi Apparatus (GA). For most eukaryotes, the GA is the penultimate stop where each protein is sorted and then shipped to its final position inside or outside of the cell. The digestive enzymes of fungi are typically found near the tips of growing hyphae. They are particularly large, with fungal cellulases being approximately 20–60 kDa.[34]

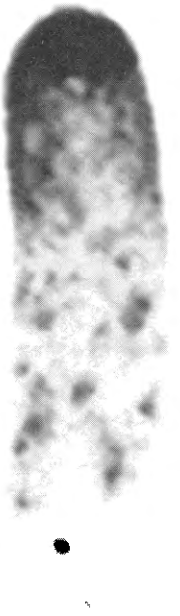
Along with these enzymes, the hyphal tip is also rich in the compounds needed to dissolve and rebuild its cell membrane and wall as the pressure of its intermycelial contents pushes it forward. New materials added to the tip quickly stream to the side and become the lateral walls that are then fixed in place. Destroying and creating itself as it searches through the world of its creation, the hypha endlessly unfolds, just like the blooming of a thousand-petal lotus.

The Mystery of Myceliation

The exact mechanism behind this tip building process is one of the most inexplicable aspects of mycelial growth. Most theories on apical extension assume that the tip is dissolved and rebuilt by compounds in the dozens of small bubbles, or *vesicles*, that cluster at the hyphal apex. While this may be true to a degree, it does not explain many other strange phenomena that occur at the tip.

Unlike what would be assumed for other eukaryotes, growth vesicles do not arrive at the apex from the compound-sorting Golgi Apparatus. Rather, they travel from the GA on microtubules to an organelle-like structure known as the *Spitzenkörper*, where they are sorted and distributed into the tip.

The Spitzenkörper is the true architect of a hypha. Taking in thousands of vesicles per minute, it rapidly sorts, processes, and then "sprays" each vesicle toward the tip interior along thin filaments of the protein actin.[35] However, this is not a random shower, as occurs with a paint sprayer. It is a controlled act that precisely places each vesicle evenly across the four dimensions of hyphal space and time. The rate of this process is staggering, with the Spitzenkörper in *Neurospora crassa* sending 600 vesicles to its apex every second, or 36,000 vesicles each minute.



This is not a constant process: there is a pulse to it similar to that found in veins and arteries and that is demonstrated by species across phyla. The slime molds *Pythium aphanidermatum* and *Saprolegniaferax*; the Zygomycete *Gilbertella persicaria;* the Ascomycetes *Trichoderma viride*, *Neurospora crassa,* and *Fusarium culmorum*; and the Basidiomycete *Rhizoctonia solani* have all been shown to exhibit a periodic rhythm between faster and slower growth as their hyphae extend. Each of these species exhibit different frequencies in their growth, with *T. viride* and *N. crassa* holding the fastest pulse (13–14 pulses per minute) and *F. culmorum* being the slowest (2.7 pulses per minute).[36]

As a hypha extends, it also branches three-dimensionally. This branching occurs when a "satellite Spitzenkörper" separates from the main Spitzenkörper, migrates backward, and, at some distance back, attaches to the side of the hypha to dissolve the existing wall and initiate a new hypha and direction for exploration. In septate fungi, this often occurs just behind a cross wall.

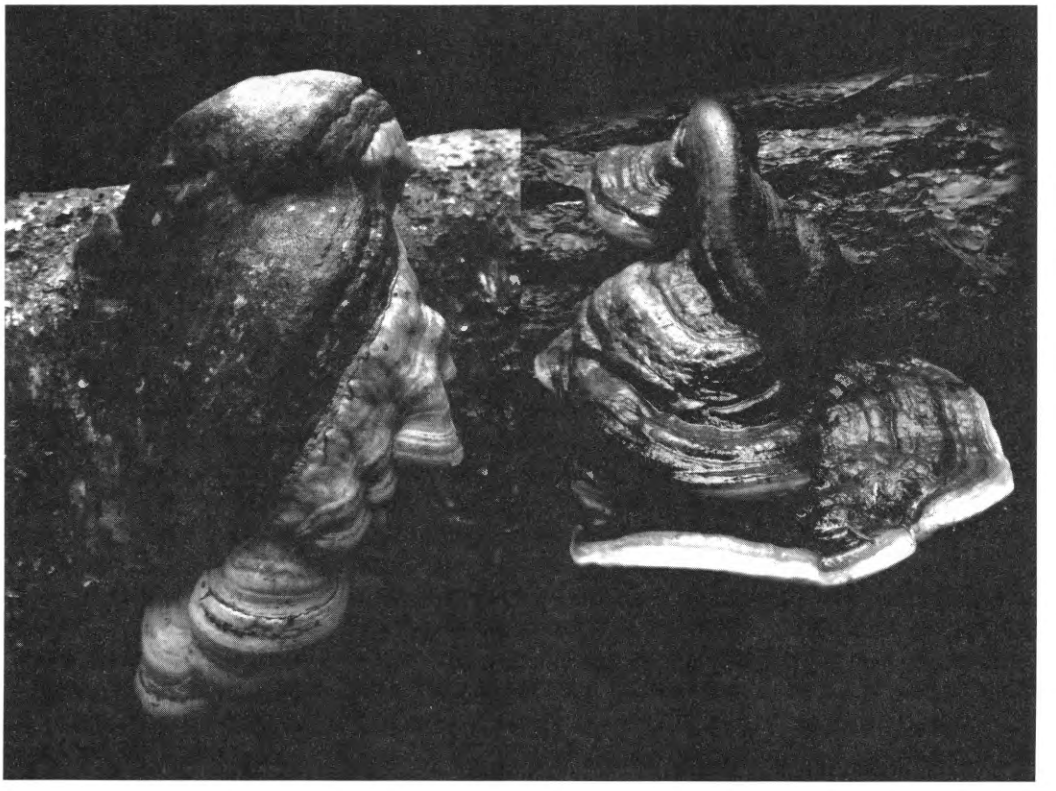
A similar process also occurs during anastomosis. Whenever two hyphae from the same network encounter each other, their respective Spitzenkörpers will gather along the hyphal tips and/or walls and seamlessly dissolve and recombine the two mycelial paths into one, creating bridges

between braches in the network. Thus, the Spitzenkörper is not only the creator and destroyer of the hyphal world, it is also its captain and navigator. What it builds, it can also take away.

All told, it is the structure of the Spitzenkörper that is perhaps its most compelling feature. For, unlike other organelles, this "organelle-like" system does not have a defined shape. It is not a discrete mass like the GA or a nucleus. It is an amorphous "cloud" of small vesicles, which may be many or few in number. This cloud may appear suddenly anywhere in the network and just as quickly break apart to form satellites or to quickly travel to other parts of the web.[37] It is an ephemeral school of mycelial thought, a mysterious flock of fungal will. During hyphal growth, the Spitzenkörper seems to take in and sort vesicles from outside itself, potentially modifying or exchanging them in the process, before precisely placing these vesicles into the 3-D space of the hyphal apex in response to environmental signals. How exactly a cloud of undefined chemicals manages this incredibly complex process is not known.

The environmental signals that guide vesicle placement come in a variety of forms. Oxygen, light, CO_2, and pH have all been shown to influence the direction of hyphal growth, though their degree of importance varies by species. For instance, though fungi do not photosynthesize, many species will grow toward light (an effect known as *phototropism*[38]), while others need some amount of light to initiate fruiting. In general, hyphae are less attracted to nutrients than they are to the volatile compounds associated with their preferred substrates. Glomeromycotan fungi grow towards volatile metabolites exuded by roots, wood rotters grow towards the volatiles released from freshly cut wood, and some pathogens grow towards the methanol released by decomposing organic matter.

When the fungus registers these compounds or other tropic signals, the Spitzenkörper will shift its position in the hyphal tip and initiate growth in a new direction that is oriented toward the signal. Somehow, the signals received by the Spitzenkörpers on one end of a network are quickly relayed across the whole mycelial network, which can respond to environmental inputs with a coordinated reorganization of the entire web and increased branching toward the signal. How this tropic sensing occurs and what exactly elicits the growth responses in the mycelium is not known. Changes in the hydrostatic pressure or amino acid concentration inside the mycelium and/or its electrical potential have been suggested as possible answers.[39]



(Above) Many slow-growing conks will envelop sticks and other plant matter in their path. Curiously, the plant often does not seem harmed by this and continues to grow unimpeded.

(Right) When the substrate of a mushroom changes orientation, the fruit body will typically change its growth direction to ensure uninhibited spore dispersal. This movement in regard to gravity is known as gravitropism.

From all that I have read on the subject of hyphal growth, electrical influences do seem to be central to the process. Like all living beings, the fungi are electrical organisms that produce their own D.C. and A.C. currents that can be altered by external signals.[40] Many fungal species are even attracted to electrical fields, an effect known as *galvanotropism*. *Candida albicans* will orient toward the cathodes of an electric field, and many mycelium-forming fungi will orient their spore germination point or hyphal branching in relationship to electrical currents.[41] The spores of *Glomus* species in the Glomeromycota produce a circulating electrical current prior to germination and germinate at the zone of outward current.[42] Growing hyphal tips produce a -200 mV inward current,[43] which may be due in part to the strong concentration of positively charged calcium ions (Ca^{2+}) located at the apex. However, the purpose of this calcium gradient or the electrical current produced by hyphal tips has yet to be adequately explained.[44]

This electrical field is not only at the edge of the culture, but also distributed throughout the mycelium, an attribute that has been correlated with communication throughout mycelial networks.[45] Disturbances to the electrical field on one end of a network have been shown to affect the other end of the web.[46] Many Asian mushroom farms are increasingly using strong electrical impulses to increase fruit body production. In one study, Nameko, Brick Cap, and inoculated logs and sawdust blocks of Shiitake were shown to double their yield when 50–100 kV were applied in a single 10 ns burst.[47] In another study, yields from Shiitake, Maitake, Nameko, Enoki, *Hypsizygus marmoreus*, Pearl Oyster, King Oyster, *Pleurotus abalones*, *Agrocybe cylindracea*, and the Cauliflower Mushroom were significantly increased by the application of short 100–170 kV bursts to fruiting substrates.[48] Fruit bodies of the ectomycorrhizal Matsutake mushroom (*Tricholoma matsutake*) almost double in number by the application of a 50 kV pulse to the ground near trees associated with the fungus.[49]

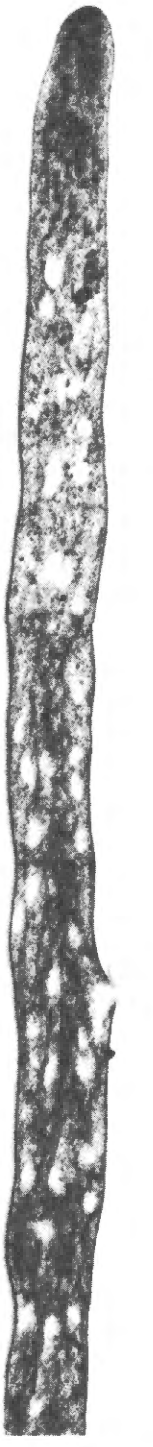
It is likely that these electrical impulses travel through the mycelium via the water that comprises much of the fungal body. Mushrooms are made of 90–92% water, but considering the small size of the water molecule, water may actually comprise around 99% of the molecules in the entire organism. Most of this water is found in the intercellular fluid, or *cytoplasm*, which is kept at a pH of 7. The ability to keep this fluid at the same pH as pure water suggests fungi hold a strong buffering capacity.

Like the flow through a watershed, cytoplasm is not stagnant in mycelium. As seen in timelapse videos of growing mycelium, the cytoplasm, nuclei, and other cellular contents of fungi rapidly stream in both directions throughout a living network.[50] The nuclei may even travel in "packets" that rapidly stream across the web, likely relaying information received from the culture's periphery. This *cytoplasmic streaming*, or *cyclosis*, is similar to how blood flows in our arteries and veins or how water travels through plant vasculature. In plants, the water flows in a bidirectional vortex of spiraling fluid. In blood vessels, the fluid vortex may be so rapid that the center third of the vessel is a void.

To enable such a rapid rate of cyclosis in the mycelium, as well as to help force each hyphal tip forward, a pressure of up to 10 atm (roughly three times the pressure in a car tire) must be built within the mycelium. This turgor (fluid) pressure is so great that growing mushrooms can lift concrete paving stones and break through three inches of asphalt. Common explanations for this pressure suggest it is caused by water and nutrients streaming into the mycelium due to osmosis. That is, the high sugar and nutrient concentration in the mycelium attracts water into the hyphae, swelling it up. As long as the strong cell wall of the fungus is maintained, a high pressure can therefore be built by this incoming flow. At the same time, so the argument goes, cyclosis is produced either by microtubules and microfilament in the mycelium contracting or by electrophoretic movement (i.e. the cytoplasm follows an electrical current in the mycelium).[51]

This intake of water and nutrients is found to occur mainly at the tips of hyphae.[52] This is striking, for, if you take a moment to think about the work that the Spitzenkörper is doing here, this situation presents a paradox: as water and nutrients stream into hyphae and build an incredibly high pressure in the mycelium, the Spitzenkörper is simultaneously breaking down and rebuilding the hyphal tip. How, then, do both of these acts occur simultaneously without the thin, constantly weakened apex exploding and releasing the mycelium's contents?

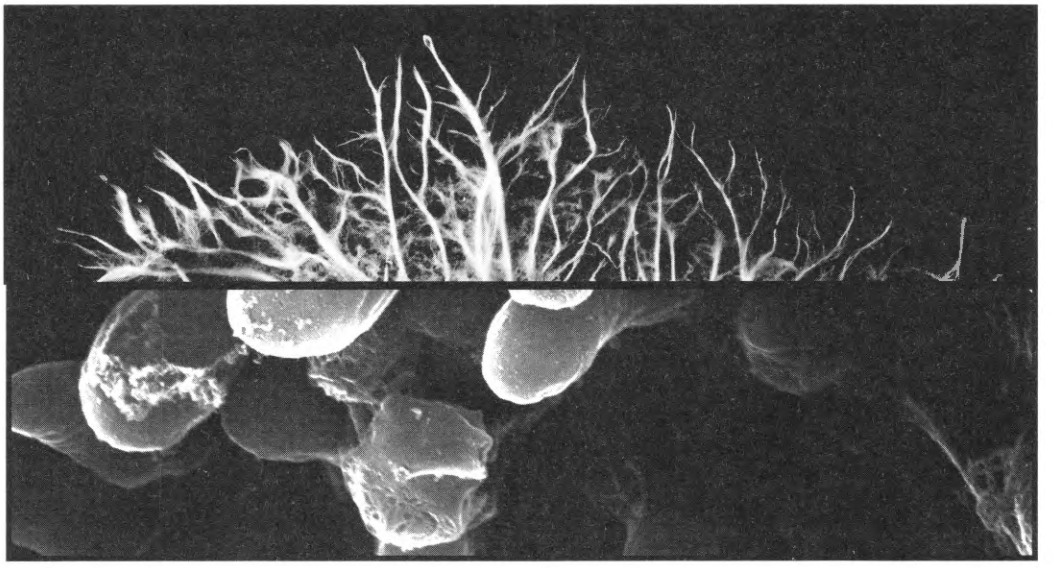
This may be the most inexplicable question surrounding hyphal growth as no current models can adequately explain this contradiction.[53] The most common theories assume one of the following:



The hyphal tip is continuously being dissolved and rebuilt by the Spitzenkörper, an "organelle-like" cloud of unknown compounds.

1. The vesicles that the Spitzenkörper releases are filled with compounds that break the sugars and chitin molecules in the cell wall apart. These molecules are then immediately rebuilt and/or extended as the pressure of the cytoplasm pushes against them. Because the vesicles may contain chitin-building materials, they may be referred to as *chitosomes*.
2. The inner pressure of the mycelium pushes the tip out, thinning it. The vesicles sent from the Spitzenkörper are thus filled with chitin and glucans, which are added to these thinned areas.
3. The cell wall at the tip is anchored inside the cell by actin filaments or similar structures, while cell membrane proteins modify the wall structure. Vesicles from the Spitzenkörper provide the building materials to these membrane proteins.

A glaring problem with these models is that they are conflicting and only account for a small portion of the growth process. Despite decades of research into the matter, there has never been an adequate explanation for the seemingly simple act of hyphal extension. Evidence of the anchoring of actin filaments suggested in the third theory has not even been demonstrated. Further, these models do not account for the electrical current that flows through the tip, the reason why growth rates pulse, the cause of cyclosis and tropism, or why nuclear packets move faster than single nuclei during cyclosis. New models for hyphal growth need to be developed that account for these phenomena in full.



ElectroMycology and the EZ Hypha

Water is one of the most ubiquitous substances in the world and also one of the most mysterious molecules in all of chemistry. Though one might assume that water is well understood by scientists, many of the chemical's unique physical properties have historically been left as unexplainable.[55]

However, this long-standing point of confusion may have recently been laid to rest. In 2013, Dr. Gerald H. Pollack of the University of Washington released *The Fourth Phase of Water*, a revolutionary book detailing a decade's worth of his research into the unique properties of water. Among his many findings, Pollack discusses that, under certain conditions, water enters a state between solid and liquid which is like a highly structured liquid crystal gel. In this fourth phase, a range of unique physical properties can be detected that not only help explain many of the strange properties of water, but also lend credence to many traditional perspectives on this substance.[56] And, I believe, this state also helps explain some of the mysteries of hyphal extension. In summary, the Pollack model of this fourth phase is as follows:

No one really understands water. The more we probe, the more puzzles come up.
—Gerald Pollack[54]

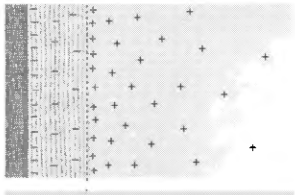
When water makes contact with a hydrophilic surface (such as the interior of a hyphal cell membrane), a negative charge is built up along a zone at the water-surface interface. This zone is made of stacked layers of hexagonally structured plates of H_3O_2 molecules. Together, these layers make this zone stiff and gel-like. And—similar to how a growing crystal or glacier expels objects—as this negatively-charged zone of water expands, it excludes compounds at least as small as 100 Da. In essence, this zone is comprised of (almost) pure water, a fact underlying the name Pollack has given it: the Exclusion Zone, or EZ.

Just beyond the negatively-charged EZ is an area of densely packed positively-charged ions (cations). These cations crowd so close that there is a strong repulsion between them, resulting in a pressure and subsequent flow in the liquid. Pollack has demonstrated this effect with tiny Nafion tubes which, when placed in water, create a perpetual flow of water through the tube, despite no energy inputs beyond those from the environment. As the EZ also pushes away almost anything that isn't EZ water, Pollack has also shown that small microspheres will be excluded from the walls of these Nafion tubes and pushed to its flowing center, much like nuclei flowing though mycelial networks.

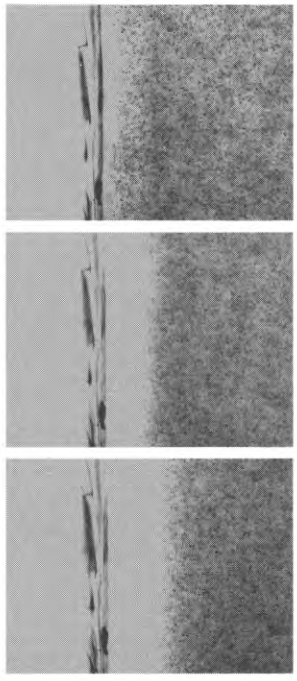
With the separation of charges between the EZ and positive region, an electrical potential difference of up to 125 mV is built in the water. This difference can be used to illuminate small light bulbs. In essence, the EZ creates a free form of energy akin to photosynthesis; it is a "water battery" that can be tapped into for hours.[57]

Like all batteries, however, the EZ must eventually be recharged. The main source of energy for the EZ is radiant energy from the environment. Infrared energy—such as that emitted by living beings, the center of the Earth, or most any physical object in our daily lives—produces the strongest EZ buildup. But visible light from artificial lights or celestial bodies can also charge the water. EZs often increase in size in the direction of a light source. Solar (diurnal) cycles and lunar eclipses also affect the size of EZs, suggesting sunlight and/or moonlight exert a strong influence on water.[58] *These effects even occur when containers of EZ water are not located in the direct path of celestial light. Through these interactions, water acts as a transducer that converts electromagnetic energy (light) into mechanical energy (work).*

The EZ effect occurs not just along flat surfaces, but also against any hydrophilic surface, including bubbles and droplets of water. Hydrophilic substances in mycelium include the interior of the hyphal cell membrane, the surface of a nucleus, and the surface of apex-building vesicles.

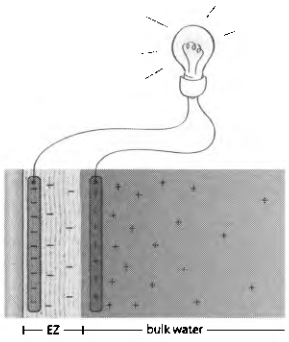


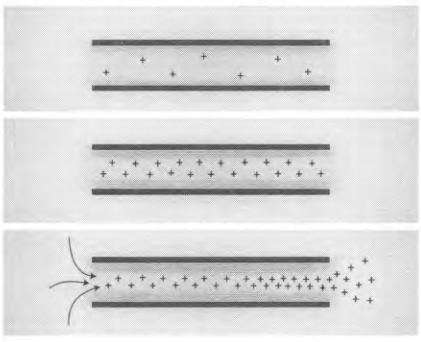
Near a hydrophilic surface, water forms a negatively-charged area, creating an Exclusion Zone that limits the entry of large molecules.



Microsphere-exclusion zone (EZ) next to a gel surface. The zone grows with time and then remains relatively stable after about five minutes.

Pollack's work has vast implications for biological, chemical, and physical sciences, leading many reviewers of his findings to regard them as some of the most important scientific discoveries of the 21st century. Biologically, the EZ effect explains how water reaches the tops of trees, something standard models of capillary action cannot fully account for.[59] It also explains how large red blood cells can be forced through capillaries that may be half their diameter.[60] Likewise, this fourth phase of water can also explain the many mysteries of fungal growth noted above. Consider the following a proposal for a new theory on the underlying mechanisms of hyphal extension:





(Left) Electrical energy generated from electrodes placed in the EZ and in the zone beyond.

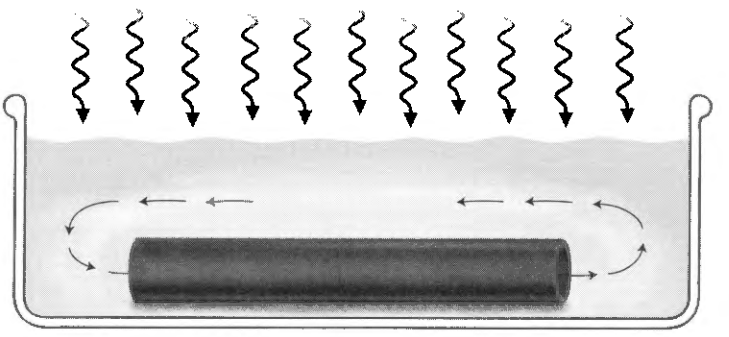
(Right) Mechanism of intratubular flow. The key element is the hydronium-ion buildup in the tube core, and its escape to the water outside.

The EZ Model of Hyphal Extension

1. Radiant energy from the environment charges the water inside of mycelium.[61]
2. Filling each hypha, this water creates an EZ along the interior of the cell membrane. This EZ excludes organelles and most solutes, forcing them to the center of the hypha.
3. A complementary positive charge builds in the center of the hypha, creating a high-pressure environment that allows for cytoplasm and organelles to rapidly move. Because the hypha is so narrow, the pressure is able to achieve a high value.
4. This pressure is contained by the strong hyphal cell wall and by the stiff EZ.
5. The EZ creates a strong net negative charge in the interior of the mycelium. Action potentials created by shifts in this charge are used to carry communication signals across the mycelial network, similar to neural networks. These may be induced in part by electrical potential changes caused by environmental signals, explaining many types of hyphal tropism, or by a water phase transition from ordered H_3O_2 to H_2O.
6. At the apex, the Spitzenkörper and the dense concentration of vesicles create a large EZ that pushes back on the mycelial cytoplasm, reducing the pressure on the apex and allowing it to be dissolved and rebuilt without exploding. The EZ also acts like an impenetrable mesh that normal water cannot pass through.[62] This effect is enhanced by the negative current produced by the apex's calcium gradient. The EZ in the tip is also attracted to light, helping explain the phenomenon of phototropism.
7. The release of positively-charged substances from the tips (e.g. digestive enzymes and protons) is made possible by their travel through the EZ inside of EZ-coated vesicles. This release of acids, along with CO_2, also helps reduce the proton pressure in the mycelium.

In other words, the pressure, circulation, and electrical charge that drive mycelial growth and communication is the product of the water that makes up the bulk of the fungus. This water is charged by energies radiated by celestial bodies and the ecosystem that the fungus plays a central role in shaping. As a mycelial network moves nutrients through the environment and expels contaminants, it permeates, purifies, and nourishes the soil web in ways that intelligently meet the innumerable needs of the ecosystem. It is, in effect, the nervous and circulatory system of the world's forests, fields, and deserts, with the radiant energies of the solar system providing the heart beat that drives its pulse.

I believe that the inclusion of the EZ theory of water into existing models of hyphal extension is the missing link to the many mysteries that have long plagued mycologists studying this phenomenon. The significant implications of this theory on processes of fungal cultivation, intra- and inter-species communication, and biostimulation need to be investigated by mycologists and cultivators, both academically and on the grassroots level. While this model will likely be refined over time, if its foundational arguments are proven correct, it will undoubtedly change our understanding of how fungi fundamentally grow and will radically alter how fungal cultivation, medicine



Charged by radient energy, a "spontaneous" flow develops through hydrophilic tubes.

production, and mycoremediation are practiced in the near future. The chemistry that underlies biology is an outcome of electrical interactions. As such, the future of mycology must be framed by an understanding of the electrical nature that underlies fungal biology. I firmly believe that such a paradigm shift will be central to creating a cascade of major advancements in mycological research, but only if others in the field acknowledge advancements currently underway in the physics of the 21st century.

All organic activities and processes of growth in any living organism, or any metabolic function associated with sustaining life of any kind is an electric phenomenon and requires elements of ion exchange. Cations (+) carrying a positive electrical charge, and anions (-) having a negative potential are constituents of acids, bases, and salts, which become active as electrolytes (or conductors of electricity) in aqueous solutions. Life in its broadest sense is electrical...
—Robert Becker, M.D.

Fungal Morphogenesis

From the sea of mycelia that weave through an environment, fungi form a wide array of complex structures. Mushrooms, mold conidia, and the white webs beneath rocks and fallen logs all build from the transformation of mycelium. These structures are not alternate tissues or organs, but assemblies of hyphal threads.

In animals and plants, the production of novel tissues is caused by specific genes and detectable hormones. However, based on current observations, it seems that fungi do not use any similar form of chemical signaling prior to the production of their various structures. The fungal genome lacks any of the gene sequences that are critical for controlling multicellular development in animals or plants. This is why cultivators cannot use chemical signals to trigger mushroom formation, but can only create a supportive habitat for a fungus and either shock it with electricity or simply wait for the mycelium to transform itself into a mass of fruit bodies. The British mycologist David Moore sums up this confusing situation quite nicely:

> *"We are ignorant of the basic control processes of fungal developmental biology; we are ignorant of the molecules and mechanisms that generate fungal multicellular structures."*[63]

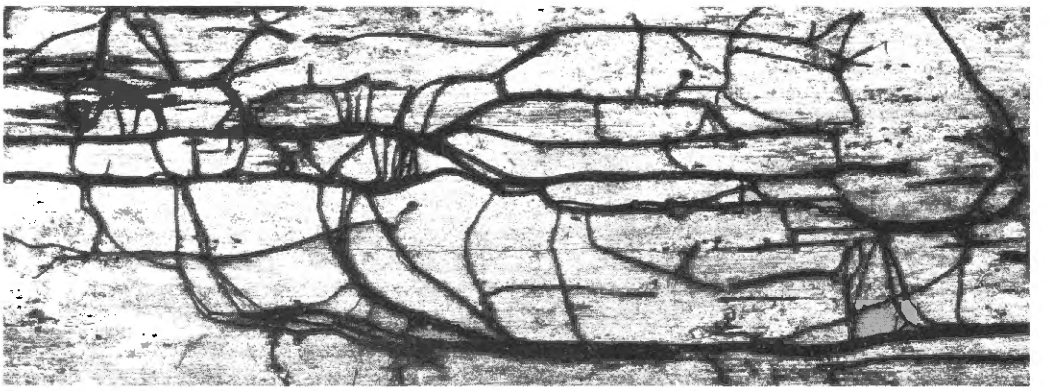
The EZ Model of Hyphal Extension may help address this problem. For, if a chemical cause of *fungal morphogenesis* cannot be supported, an energy-influenced intermycelial signaling system should be investigated for its potential to form the fungal "language" that humans have yet to decipher. This energy could be transmitted through the mycelium as electrical currents or it may be transmitted as electromagnetic radiation (light). As demonstrated by numerous studies over the past few decades, plant, animal, and bacterial cells all produce, communicate with, and are influenced by low levels of light known as "ultraweak bioluminescence," or "biophotons."[64] For example, external light sources can influence communication across the neural cells of rats.[65]

However, as far as I am aware, research into light-based communication systems between mycelia and their environment is non-existent. While it is known that specific frequencies of light initiate mushroom formation in some species, it is not understood why these specific wavelengths are required. It is my opinion that this topic needs to be investigated by researchers. If it proves critical to fungal growth patterns, it could revolutionize our understanding of how fungi form mushrooms, produce medicinal compounds, and degrade pollutants, as well as how to induce those changes externally.

MycoGenesis

Mycelia take on a striking array of colors, shapes, and patterns. The mycelial mats of molds and mushrooms can be circular, irregular, spiral-shaped, ringed, uplifted, matted, whispy, or combinations of all of these. Many species have white mycelium, though others may be lilac, red, or yellow.

Of the structures produced by mushroom-forming fungi, some of the most common are dense collections of hyphae. Some species cluster hyphae by the thousands into *mycelial cords* to rapidly shuttle nutrients across long distances and nutrient-poor zones. Other species form *rhizomorphs*: thick, rope-like structures that are denser and more complex than mycelial cords. These usually have a large central channel for conveying materials and information along with a relatively thin, external "rind" of pigmented mycelium. Honey Mushrooms (*Armilaria spp.*) form very thick and dark rhizomorphs that, at up to four millimeters or around 4,000 mycelial strands thick, look like a web of black bootlaces wrapped around a log or tree trunk.[66] The dry rot fungus (*Serpula lacrymans*) forms rhizomorphs that can travel across all types of building materials and even penetrate into several meters of masonry in search of food.[67] In tropical rainforests, various *Marasmius* species (e.g. the Horsehair Fungus [*Marasmius crinis-equi*]) form a network of aerial rhizomorphs that span the tree canopy to collect and digest falling leaves. These fungi in the sky develop a sporulating fruit body cap at the tips of these rhizomorphs, essentially making each rhizomorph an indefinitely extending stipe.[68] Tropical birds also use these nets as a nesting material.[69]



Sclerotia are another mycelial structure produced by some fungi. As dense balls of mycelium, sclerotia look similar to truffles. However, sclerotia do not contain spores but an inner medulla of woven hyphae and an outer rind, which may be darkly pigmented due to an accumulation of melanin. Sclerotia primarily serve as a long-term nutrient storage system from which many species (e.g. *Morchella spp., Claviceps purpurea, Wolfiporia extensa, Pleurotus tuber-regium,* and *Psilocybe mexicana*) produce mushrooms, arguably the most elaborate fungal structures.

For Basidiomycetes, mushroom formation is so refined that three distinct types of mycelium may be used to construct a fruit body. All of these mushrooms contain the thin-walled, septate *generative* hyphae that may or may not host clamp connections. Others also contain *skeletal* hyphae that are either thick-walled with widely spaced septate and lacking clamp connections, or swollen in the center of segments. The third type is the thick-walled and frequently branched *binding* hyphae. Mushrooms that only contain generative hyphae are called *monomitic.* They tend to be soft and fleshy, like most edible mushrooms. *Dimitic* species are comprised of two hyphal types; most contain generative and skeletal hyphae, though *Laetiporus* species uniquely contain generative and binding hyphae. Species with all three types of hyphae are *trimitic* and tend to be woody and leathery, as with the polypores. If you consider mushrooms as merely a means for spreading spores, as many mycologists argue, it must also be admitted that they are some of the most complicated structures used for procreation.

Regardless of species, the process of mushroom formation is essentially universal. From an undifferentiated mycelial mass, a cluster of cells first forms. Quickly, this small bump in the ocean swells with fluids and rises to take on the shape of the emerging mushroom. Even at this tiny stage the outline of fruit body may be visible—a homuncular ghost of the mushroom to come. *Coprinus cinereus* can be recognizable in its basic form when it is only 800 μm tall, or a mere 1% of its mature size.[70] As the primoridia swells, the mature fruit body breaks from the shell of its childish impression, often in just a few short days.

Most cultivated mushrooms are the product of a single dikaryotic network. But occasionally, as many as nine or more genetically distinct mycelial networks will coordinate their hyphae to form a singular, spore-bearing mushroom.[71] These various different strains do not fuse their mycelium during this process, but only intertwine them. Growers of *Psilocybe* mushrooms commonly witness this phenomenon. Though it is possible that this collaboration could be the result of chemical signaling in the interhyphal space, I have not found any evidence of this occurring. As such, I suggest is it also plausible that this phenomenon is influenced or fully induced by biophoton-based communication. Further, if this theory were proven correct, it would not only help explain communication between hyphae of differing strains but also between differing species, further extending our understanding of how fungi coordinate the health of an environment.

MycoImmortality

If provided with enough nutrients and a supportive environment, a mycelial network may continue to grow endlessly.[72] Any part of that network—whether in its distributed form or condensed into a fruit body—is *totipotent*, meaning that it can be removed and placed in a new environment to regenerate and create an exact copy of the network it came from.

Fungi are also incredibly adept at responding to their environment. When placed under novel conditions, a given fungus can adjust its defensive and digestive strategies to match the demands of their new environment. This adaption process can be repeated for as long as the basic fungal needs (e.g. food, air, warmth) are provided, a fact that lies at the heart of fungal cultivation practices. In essence, mycelium is a mass of identical stem cells with the ability to continually adjust to a variety of conditions. Such a degree of resiliency, determination, and genetic mastery is not found in any other group of eukaryotic organisms.

As mycelium grows, it also makes conservative decisions about how it will expend its resources. Older, non-productive regions of a network may have their septae closed and nutrient flows restricted,[73] a self-culling that folds aged hyphae back into the nutrient cycles of other organisms. Similarly, if a network is broken by a disturbance to its habitat, the broken ends of a hyphal thread will constrict their septae to limit the loss of cytoplasm. Days or years later, the resulting mycelial islands may encounter each other and readily fuse together to reform a cohesive web. If enough time has passed, each island may have adjusted its enzymatic expressions. Such alterations, or epigenetic "lessons," may then be shared when the two separated mycelial masses reunite.

When dried or placed into nutrient-depleted water, mycelium of many species will enter a state of suspended animation. The fungus may be able to remain in this state for decades, only to later be reanimated and grow with the same degree of vigor it originally held. After being dried for years, mushrooms of *Marasmius oreades* can be rehydrated and readily begin cellular respiration and the production of spores. Similarly, the spores and thalli of various molds and lichens are well-known to be unaffected by the extreme conditions of interstellar space.[74]

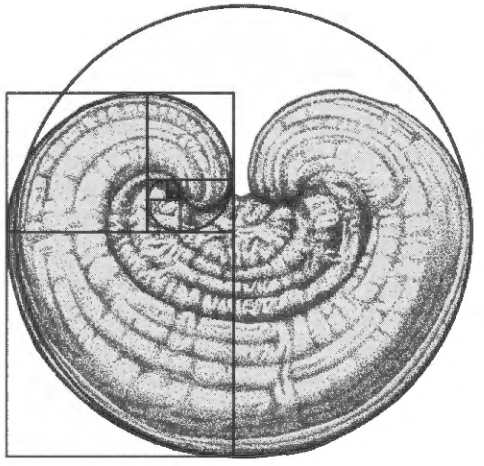
Thus, with no predetermined or maximal age or size, fungi are unbound by the constraints of time and space. They are the time travelers and shapeshifters of the world who have carried the history of the Earth in their DNA through all the great extinctions of the past. As we now find ourselves in the midst of one of the most tumultuous times in human history, humility is needed to heed the lessons of these ancient keepers of the world, and to explore the patterns that they have always expressed about Nature and of living in accord with its principles.

The Geometry of Fungi

As with all great teachers, the fungi's most profound lessons are subtle. For beneath their physical acts lays another set of patterns that not only express lessons about fungi and humans but, more deeply, something intangible about Nature itself. Many ancient cultures saw the beings and actions of the world as embodiments of forms and numbers that underpin the universe—archetypal qualities that could be contemplated to better understand the external world as well as one's body, mind, and spirit. Through number and geometry, it was said one could discover the essence of being. Such study was often applied to the forms of animals, plants, and inanimate objects. But for reasons unknown to me, the geometry of fungi was never examined, despite the many patterns they hold.

To the ancient Egyptians and their students, the Greeks, one of the most important patterns of Nature was found in the various expressions of the ratio *phi*. Commonly known as the Golden Section or Golden Cut and expressed numerically as 1.618 (033988...), phi underlies the proportions of the human face, ant bodies, and the codon frequency of DNA,[75] to name but a few examples. It is the perfect ratio, found throughout the pentagram, a shape that was for the Pythagoreans the ultimate symbol of life and the embodiment of all of Nature's teachings.

In the fungi, phi is found in the dimensions of an ovoid spore, in the ratio of a cap to its stipe, in the curve of the Reishi conk, and in the unfurling of a mushroom cap. As key holders to the bridge between life and death, fungi combine Earth, Water, Wind, and Fire to manifest as the fifth element or quintessence: Aether. Perhaps this is why Pherecydes, teacher of the mathematician and mystic Pythagoras, deemed the center of the pentagram *pentemychos*, the place from which all life was born.



As the mushroom manifests, it takes on the shape of the world's most powerful generative forces. Found in the gases of nebulae, in the clouds above volcanic eruptions, and in the development of the uterus and phallus, this iconic shape is the Rayleigh-Taylor Instability. It occurs wherever a fluid collides into another of greater density, just as when Aether pushes into matter.

Replete throughout these and other fungal forms is the circle—the most perfect 2-D shape—and it's twin the sphere, the most elegant of the three-dimensional forms. With the shape of the Sun and Moon, the circle represents the heavens as well as its manifestation on Earth. It is the container of everything and the nothingness from which all things are born. It is the wheel of time turning endlessly around the single moment and the center of the eye that sees it all.

In the Queendom, the circle appears as the secret door of fairy rings formed by round-capped mushrooms at the edge of an ever-expanding disk of mycelium. Roundness is seen in the bottom of the bird's nest fungi, in the spherical spores of globe-shaped *Calvatia* puffballs, in the cleistothecia of Ascomycetes, and in the cross section of a hypha, stipe, or *Hericium* tooth. Temporally, the circle is experienced in the annual return of the foray, the pulses of hyphal growth, and the flow of carbon between mycorrhizal partners.

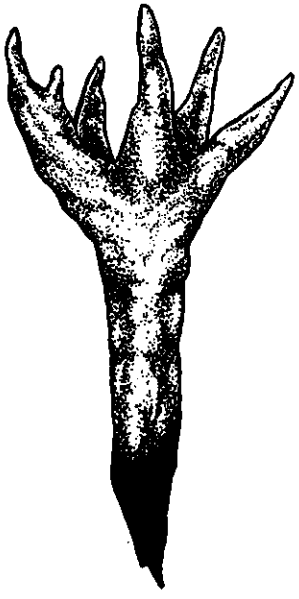
In the center of the circle is the single point, an ancient symbol of the individual life surrounded by the whole of the universe. It is the singular mushroom that arises from networks connected both spatially to a habitat and through time to ancestors and the countless generations that its spores will spawn. From the mycelial sea of imagination and endless potential, the mushroom forms as a perfect creation—a point of coherence in the endless cycle of time.

Circles expand outward and form spirals, the symbol of progress and time moving forward. The spiral is seen in whirlpools of water, the phyllotaxis of leaves, in the evolution of an ecosystem over time, and in the movement of Earth through space. In the fungi, the spiral expresses in the aquatic spore catchers of *Helicodendron* and *Helicoom* species, and likely in the cyclosis of glomeromycotan hyphae and *Armillaria* rhizomorphs. Spirals form the backbone of medicinal glucan sugars in the cell wall of fungi. A triple helix with a pitch and sense similar to DNA, these sugars form a mandala with a central axis spaced in accord with the Golden Section.

Throughout Nature a common pattern is symmetry, that ubiquitous yet elegant balance of halves and subtle harmony. Hyphae, spores, yeasts, and many mushrooms all exhibit the principle of dorsiventral symmetry, as seen in animals. Other fungi, such as the Hawk's Wings mushrooms and earthstars, form rotational symmetries, like that found in the display of flower petals.

But tied to symmetry is its dual: asymmetry. We see dualism throughout the fungi. It is found in the constant destruction and creation cycles of hyphal expansion, in the role changes of endophytic fungi to parasites, in the Sun and Moon correspondences of *Amanita muscaria*, in the mating of hyphae, and in the straight line of the mushroom stipe that projects into the receptive curve of the fruit body's cap. The greatest contrast, however, is found between the intricate and structured mushroom and the asymmetric mass of mycelia from which it is born. Just as order balances chaos, the mushroom takes form from this void of primal thought—an ecstatic expression born from ascetic meditation.

Here, in the all-pervasive, connected, and wise mycelium do we find the most profound lessons of the fungi. To ancient Chinese scholars, the netted and broken patterns found in mycelium and throughout Nature were known as *li*, a form long considered to contain the process that shapes matter out of the dynamic Tao. Indeed, it is a behavior pattern that comes about when one is in accord with the Tao. It is in the veined patterns of rocks, in the cracking of desert mud, in the breaks of lightning bolts and coastlines, and in the patterns that water forms as it runs down windowpanes. Li is in the branching of the circulatory system of animals, the spread of Yarrow flowers, and the textures of bone, wood grain, and tree bark. It is in the invisible web of subatomic vacuum and in the relationships between lives and landscapes. Mentally, our thoughts and memories also weave and branch this way, constantly intersecting with the past to relay new ideas through dreams and imagination. In the fruit bodies of mushrooms, li is found in the labyrinth of Morel apothecia, the coral branching of *Ramaria* species, and in the tips of *Xylaria hypoxylon*.



The term Tao refers to the vast and great; the term Li includes the innumerable veinlike patterns included in the Tao... It is also like the grain in bamboo. On the straight is it of one kind, and on the transverse it is of another kind. So also the mind possesses various principles.
—Chu Hsi (1130–1200 CE)

Li is the gestalt, more than the sum of its parts. Neither creative nor destructive, li structures just are. Such is the way of mycelium. Totipotent, each hypha is a hologram, a small reflection of the whole that it holds within itself—a microcosm of the holographic universe.[76] As with all li patterns, mycelium puts order to the seemingly chaotic. It draws our eye in for, although we see it, we also know that there is no way of defining it. Mycelium must be experienced to be understood.

Perhaps this is why cultivating fungi is so fascinating. As the cultivator watches the mycelium express itself, she does not watch a single organism grow. Rather, she is witness to an archetypal expression of the universe, a microcosm of life that can be viewed up close and in real time. As the growth proceeds, the cultivator constantly influences the fungus, while being influenced by the fungus in return. The art of cultivation is a reminder of this constant ebb and flow of existence.

The li in mycelium releases us from the need to put rigid structures and maps upon the world, and to embrace the potential in exploring the many wondrous roads that lead toward an unknowable future. In hyphal time, there is no set path to follow, no predetermined destiny. Each strand is where it is meant to be. Some run parallel for a while, others may intersect, but most diverge and adapt as they learn to expand in the universe of soil, knowledge, and unlimited experience. This is but one expression of the Way of fungi.

Chapter Two

Fungi Being

Things we call parts in every living being are so inseparable from the whole that they may be understood only in and with the whole. —Goethe

In nature, a whole encloses the parts, and yet a larger whole encloses the whole enclosing the parts. By enlarging our field of view, what is thought of as a whole becomes, in fact, nothing more than one part of a larger whole. Yet another whole encloses this whole in a concentric series that continues on to infinity.
—Masanobu Fukuoka

In the evolution of Gaia (the living planet), it is now clear that most of the critical planetary functions are performed by microbes capable of surviving the greatest catastrophes. All the complexity of advanced plants and animals is the icing on the cake of life... —David Holmgren[1]

From the depths of the ocean, to the frozen cliffs of Antarctica, to the rainforests that band between the tropics, fungi are found in complex associations with all the world's inhabitants. Through these interactions, fungi uphold a plethora of vital roles in the development, evolution, and maintenance of the belowground and aboveground communities that the soil horizon intersects. They nourish the land, constrict the spread of disease, and increase the connectivity and distribution systems that enhance an ecosystem's resilience. In effect, hidden hyphae slowly and subtly guide the unfoldment of all ecologies over eons.

Fungi build and design the world around us, often acting as the primary instigators and stewards of many biogeological cycles. And yet their significance is frequently obscured in environmental studies by the more apparent impacts of animal and plant habits and geological shifts. This knowledge gap in the natural sciences has not only led to vast flaws in ecological models, it has enabled the development of detrimental and short-sighted plans for the extraction of natural resources, the production of food, and the protection of wild spaces. As long as fungi are forgotten, such missteps are bound to continue unimpeded.

Thankfully, one's awareness of fungi can quickly be expanded by a study of the many roles they take on in the environment. Once the ecological functions of fungi are understood, it becomes clear that they should be celebrated for the various ways that they rotate nutrients through an environment and ensure species succession—two influences that significantly enhance ecological resilience. Such actions are critical to the continuance of all life, placing fungi at (or at least near) the center of any discussion on microbes, plants, or animals, where countless intersections are found.

Where reductionist paradigms divide the world into simplistic parts, fungal systematics remind us that no life form or cycle can be untangled from its environment. It is only through the interactions of the various subset systems of the world (the "sciences") that the reality we experience expresses itself as life. Likewise, most fungi perform roles that are multi-faceted or dramatically altered in response to external systems, a fact that sharply contrasts with their textbook segregation

into artificially discrete niches. The ecological roles of fungi are primarily *emergent properties* that are only expressed by the interplay of genes, microbes, plants, animals, and environments—fungal emergence as environmental epigenetics.

Through their study, fungal systems remind us that the global biome is a complex of interconnected and nested systems built by animate and inanimate beings that all influence, and remain influenced by, the hyphal pressures around them. This knowledge inevitably leads to the realization that such connectivity is not only commonplace in the universe, but necessary for Nature to persist. As such, many Radical Mycologists find that their interest in fungi leads them to become ecologists, naturalists, conservationists, systems theorists, and, for some, devout defenders of all life.

The Mycorrhizosphere

Our exploration of fungal systems begins with a cross-section of soil, the hidden ecology. Underground and subcultural, soil communities build the world we stand upon and sustain the life that fills all biomes. They are the earthly womb from which life springs and the dark tomb to which all things return. A universe of unfathomable complexity, the soil is filled with innumerable organisms performing invisible acts that, despite countless influences, somehow remain finely balanced and forever abundant.

Soils are the history books of the world encoded by fungi, microbes, and insects into each chapter of leaf and rock. To read this story, the soil requires us to examine the unknown, to seek subtleties in expression, and to uncover complexity through a blend of sharp awareness and the ability to wonder. Without offering the soil the chance to unveil its countless dynamics, it will only appear as a dead, static mass of minerals, the way it has to scientists for the bulk of agriculture's modern history.

With over twice the biomass of all of Earth's animals,[2] soil is truly alive and can, in a sense, be regarded as a sort of massive organism. Like all living beings, the soil takes in, transforms, moves, and releases nutrients for other organisms to consume. But, more critically, the soil is the central axis in these nutrient cycles. It is through soil that carbon, nitrogen, and many other elements complete their resurrection from decay back into living matter. The soil is the bridge that links the largest organisms with the smallest microbes, just as the air we exhale is endlessly inspired by other animals and plants.

Soil cannot be created in a lab, nor should it be seen as the sum of its components. Indeed, the vast majority of soil organisms cannot be intentionally cultivated, their lives being inextricable from the soil body. The habitat of these microbes—the inanimate aspect of the soil web—is ancient, being born over eons by the slow reduction of organic matter to small substances, collectively known as *humus*. Humus takes such a long time to accumulate that it may only reach a depth of one meter in an old growth forest, while it is often only an inch or two deep in developed areas. With such a small amount of topsoil on the planet, this protective layer of the Earth must be spoken for, understood, and held sacred by all those who care for the wild. It is the skin of the world, tattooed with the legacies of its inhabitants. But just as our skin can be easily wounded, so too is the soil readily broken and scarred if not defended from injustice. To talk of any ecology or its protection is to speak of soil, so precious is its connection to the web of life.

As with most soil microbes, the diversity, distribution, and dynamics of soil fungi are barely understood. Soil yeasts offer a significant contribution to nutrient cycles and also provide a food source for other microbes and insects, yet to date they have received limited attention by ecologists or mycologists.[3] The mycoparasitic *Trichoderma* species are highly abundant in soils, performing a critical "check and balance" function amongst soil fungal populations. And yet mushroom growers who don't realize their importance come to despise these species for their unwanted growth on mushroom mycelium in the lab.

The soil fungi that are by far the best understood are those that form a mutually beneficial relationship with living plants roots. Through the entanglement of their hyphae with delicate root hairs, various fungi from multiple phyla form a *mycorrhizal symbiosis*, a fungus-plant dynamic that is shared by more than 6,000 fungal species and at least 90% of the world's plants. Mycorrhizal fungi are found in all habitats and latitudes permeating the soil matrix. Where wild soils remain intact, a single gram of Earth may contain 1,000–10,0000 fungal propagules and a mile or more of hyphae. A single acre in an aged Douglas-fir (*Pseudotsuga menziesii*) stand can contain 3,700 pounds (1,680 kg) of mycelium by dry weight and 4,800 pounds (2,180 kg) of mycorrhizal rootlets.[4] This ubiquity results in a wide range of benefits to not only the organisms involved but to the entire ecosystem in which they are enmeshed.

The point of connection between the two organisms, the *mycorrhiza*, is not defined by the fungus or the plant that the fungus inhabits. Rather, a mycorrhiza is the singular, symbiotic partnership of the two beings. Mycorrhizal structures come in several forms, though all hold the root-hypha intersection as their central feature. In all instances, the mycelium wraps around the plant's root tips and enters the root cellular structure to a depth of at least the first few cell layers. Typically, mycorrhizae develop on undifferentiated root hairs (meristems), where the plant absorbs the bulk of its water and nutrients.

Some mycorrhizal fungi only enter the root to a shallow depth. These are the *ectomycorrhizal* species, many of which form edible and medicinal mushrooms or truffles. Other species travel deeper into the root's structure and penetrate the walls of root cells. These are known as *endomycorrhizal* fungi. Some endomycorrhizal fungi do not form mushrooms but live cryptic lives beneath the soil horizon.

In all mycorrhizal structures, nutrients are passed between the two partners. The mycorrhiza is like a barter station where each species provides something of value that the other could not obtain on its own. With its ability to photosynthesize, the plant reaches toward the sun and creates sugars that it sends down to the fungus. In return, the slim and quick-growing hyphae extend far into the soil matrix to draw in water, nitrogen, phosphorus, and other nutrients that the thick and slow growing root hairs would not be able to easily reach on their own. In effect, the fungus expands the absorptive area of the plant roots 10–1,000 fold, thereby increasing the growth rate and survival time of the roots, while decreasing the time it takes for the plant to reach maturity. The benefits of this enhanced nutrient access include a higher nutritional content, medicinal quality, and flowering rate in mycorrhizal plants when compared to non-mycorrhizal plants of the same nursery stock.

This increase in absorptive surface area is not the only way that these fungi enhance nutrient access. If it were, plants would likely have evolved to produce longer or slimmer roots long ago. Fungi produce a unique array of digestive enzymes and acids that are able to unlock nutrients that would otherwise be unavailable to plants. These nutrients may come from organic (carbon-containing) substances, such as plant and animal debris, or they may be bound in inorganic (non carbon-containing) substances, such as rocks and clay. Through their digestive abilities, fungi transform these nutrients from a non-soluble, or "unavailable," form into a water-soluble, or "available," form that plants can readily take up into their tissue and metabolize. The fungi transmute inert substances into nourishment, channel these compounds through their mycelial networks across the soil, and provide them to whole plant communities and ultimately to the entire ecosystems that the plants inhabit. And when these plants die, they are churned back into the soil matrix by decomposing fungi where their nutrients eventually pass on to other organisms.

Unable to access distant or non-soluble nutrients, many plants (e.g. grapes, citrus, melons, oaks, and pines) fail to survive without a mycorrhizal partner. This is because most plant roots have

not evolved to perform the chemical transformations that release soil-bound nutrients. Roots are essentially porous anchors that primarily stabilize the plant and serve as a beacon and platform for the beneficial microbes and fungi that actually produce and provide much of the plant's nutrition.

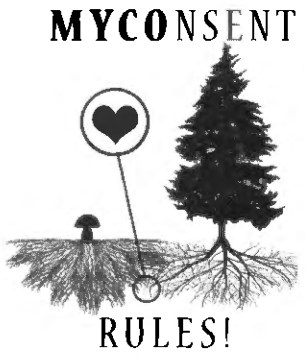
Where mycorrhizal fungi are absent, most plants must be fed with water-soluble fertilizers to obtain their basic nutrition. However, the extraction, industrial processing, and transglobal shipment of both artificial and natural fertilizers incurs a range of significant and hidden social and ecological costs, making them unsustainable options for enhancing crops. Fertilizers also tend to be applied in excess, resulting in a significant loss of nutrients that wash past root zones. These excess fertilizers then leach into ground and surface water systems where they disrupt soil ecologies and flood into river deltas to feed blooms of toxic algae that choke out other aquatic life. Problems such as these can be avoided in food production systems through the use of compost and the cultivation, inoculation, and stimulation of mycorrhizal fungi.

This relationship has numerous other effects. As mycorrhizal fungi are able to tolerate lower water levels than most plants, these species can reduce a plant's dependency on constant water access, thereby reducing the drought stress that would otherwise cause non-mycorrhizal plants to wilt and die. This is especially important in desert ecosystems where cacti and most other plants rely heavily on mycorrhizal fungi for their hydration and survival.[5]

Mycorrhizal fungi also provide plants with protection from soil pathogens. The mycelial coat around the root acts as a protective "shield" against antagonists, while the fungus may also release antibiotic compounds into the mycorrhizosphere that are targeted to specific pathogens. Mycorrhizal fungi can also indirectly suppress pathogens by competing for nutrients (e.g. with the production of chelating siderophores), by influencing the plant's production of its own endogenous defense mechanisms[6] (e.g. by increasing the root's production of lignin[7]), and/or by stimulating the growth of other beneficial microbes. In effect, mycorrhizal fungi not only help increase the plant's overall resilience against attack, they also reduce the need for plant growers to apply natural or artificial pesticides that disrupt the delicate dynamics of soils.

As with many aspects of the soil web, most mycorrhizal relationships are not one-sided or monogamous. The plants involved are not passive to their fungal partner, nor will they pair with just any fungal species. Prior to the mycorrhizal formation, the plant and fungus communicate with one another through an exchange of chemical signals, and if the plant decides it wishes to partner with the fungus, it will allow it to enter[8]—only after consent is given does penetration occur. As a plant ages, it may disassociate from a fungal partner and start partnering with another. Similarly, a single plant may host dozens of species at a time or throughout its life. A single Douglas-fir (*Pseudotsuga menziesii*) tree may host 50 mushroom-forming mycorrhizal species at any moment[9] and over 200 mycorrhizal species during its life. Over 2,000 mycorrhizal species are known to associate with Douglas-fir trees, about 10% of which are not likely to be found with any other tree partner.

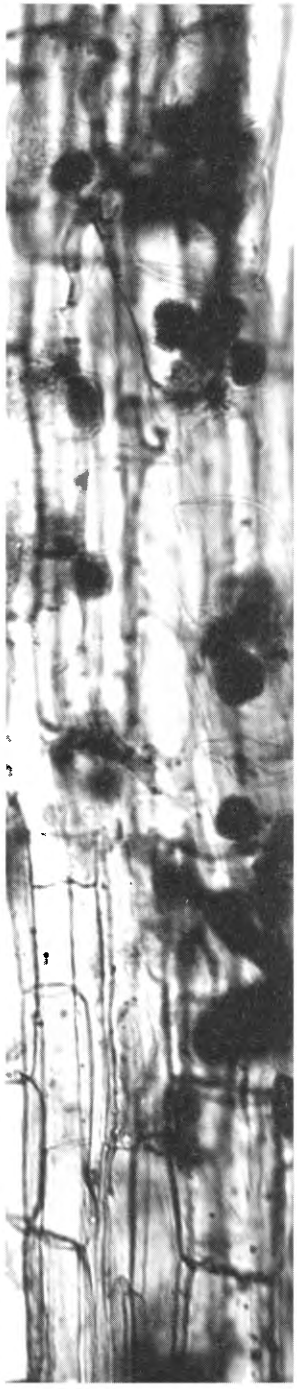
Through mycorrhizal relationships, fungi unite the ecologies of the world. Where soils remain undisturbed, these partnerships do not remain limited to combinations of one or multiple fungal species and a singular plant. Mycelial networks can connect the roots of dozens of plant species across phyla within an ecosystem. They are the connective tissue that ties whole ecosystems together through a Common Mycelial Network (CMN) in which nutrients, water, and information are constantly exchanged between organisms large and small. In dense forests, mycorrhizal fungi have been shown to carry sugars produced by elder trees to seedlings that would otherwise die in the dense shade of the understory.[10] In one study, a similar type of nutrient sharing was shown to occur between a Douglas-fir tree and a paper birch (*Betula papyrifera*), first in one direction and then in the other.[11]



As these interactions increase in complexity over time, it must be recognized that mycorrhizal fungi are not merely looking out for their immediate nutritional needs. Mycorrhizal fungi perform a range of metabolically taxing acts that do little to serve themselves in the short or long term. Through their work, mycorrhizal fungi act as central drivers in the cycling of the world's nutrients;[12] they are the microbridges that sustain whole plant communities and enable life to flourish in some of the most extreme environments on Earth. In forests, fields, and deserts, mycorrhizal fungi act as keystone species that stitch together the fabric of a habitat and pull it forward through time. And

if they had never evolved to assist the movement of plants onto land (a topic discussed in Chapter 3), life as we know it would not exist on Earth. Mycorrhizal fungi are the keepers of the wild and the protectors of our biomes. They are the unspoken stewards of habitats, constantly balancing an ecosystem's plant, animal, and microbial communities to assist in its spiraling succession through every climax extreme and complementary lull of blight. It is to these hidden fungi that we are the most deeply indebted.

The term "mycorrhiza" was coined in 1885 by the German botanist A. B. Frank, who first described the relationship.



The Seven Types of Mycorrhizae

The following pages detail the seven recognized types of mycorrhizal associations. However, the type of mycorrhiza a fungus or plant may form at a given time can vary in a number of ways. Many plants—and even individual roots—may host multiple types of mycorrhizae simultaneously. A given fungal species can also form different types of mycorrhizal structures, depending on the plant it is associating with.

Arbusuclar (Endo)Mycorrhizas (AM)

All species of the Glomeromycota (ca. 169 morphospecies).
At least 85% of all plant species across phyla (including two-thirds of all land plants and 90% of all vascular plants). This includes plants in the Bryophyta, almost all groups of Pteridophyta, all groups of the Gymnospermae, and the majority of families in the Angiospermae.

With fossil evidence dating to approximately 450 million BCE, the AM symbiosis is by far the most ancient of all mycorrhizal relationships. Since it first arose in early land plants, the AM association seems to have hardly changed, despite the explosion in plant diversity over the eons. Today, AM are found in abundance associating with nearly all of the world's plants and plant communities. In grasslands, they may increase plant diversity by up to 30%. And in desert environments, AM are critical for plant health and hydration, especially cacti, which have thick fleshy roots and few or no root hairs.

As "generalists" that can associate with many species of plants simultaneously, AM fungi can intimately connect the majority of plants throughout an entire ecosystem[13] and form an indefinitely large CMN to distribute resources and information amongst all those involved. In one square meter of soil, the surface area of AM mycelium may be as much as 90 m^2. More so than any other mycorrhizal type, AM may be major determinants of the plant diversity and assemblage in the habitats that they fill.[14] If any fungi are said to rule the world, it is the secret society of the arbuscular mycorrhizae.

Recognizing these impacts, the AM relationship has been so thoroughly investigated for its ecological and economic significance over the last few decades that it is by far the most thoroughly studied symbiosis that plants form, fungal or otherwise.[15] Significant attention has been given to their influence on plant growth and fertilization. Many plant crops are improved by AM inoculation, with the growth rates of maize, wheat, barley, and onions increased by two, three, four, and six times, respectively. AM fungi can reduce nitrogen and phosphorus fertilization by as much as 30–40%.[16] And they are some of the only fungi that can perform the energy-demanding process of reducing nitrate into a form of nitrogen that can be metabolized.[17]

AM have been shown to defend against many root-infecting pathogens, such as various *Fusarium* fungal species and *Phytophthora* water mold species. *Fusarium* species can be 3–10 times less abundant in the roots zones of AM-associated tomato plants when compared to non-mycorrhizal tomato plants.[18] However, because most root-pathogenic fungi infect roots more rapidly than AM

In desert ecosystems (left), arbuscular mycorrhizae (above) enable cacti to access water and stay alive.

fungi, the mycorrhizal association should be pre-established to reduce pathogenic infection. In one study, AM fungi were shown to transmit information between tomato plants connected by a CMN: when some plants were attacked by aphids, other plants in the CMN began producing endogenous antipathogenic compounds.[19] By influencing the defense behavior of plants, these fungi indirectly create a cascade of effects on herbivores and their natural enemies, influences with widespread and indeterminable ecological significance.

On all continents except Antarctica, AM fungi are found inhabiting grasslands, forests, deserts, aquatic environments, salt marshes, and most other ecosystems. They are common at lower elevations where neutral or slightly alkaline, mineral-rich (alluvial) soils dominate, flora and fauna diversity is rich, and rainfall is less abundant.[20] In agricultural sites that are constantly tilled, heavy-sporing *Glomus* species tend to dominate as they do not rely on hyphal spread to reach new plants as much as other genera of AM fungi.[21] The Glomeromycota are highly adapted to forming AM associations: their DNA holds over 100,000 genes related to the symbiosis.[22] Compared to other types of mycorrhizal fungi, AM are quite easy and inexpensive to cultivate.

Ericoid Endomycorrhizas (ERM)

Several genera in the Ascomycota.
Plants in the Ericaceae, including those in the genera Erica *(heather),* Calluna *(ling) and* Vaccinium *(various productive berry plants).*

These mycorrhizae form on all continents except Antarctica, generally in high elevation grasslands, tundras, heathlands (moorlands), and boreal (taiga) forests. These extreme environments are characterized by nutrient-poor and very acidic soils. Some of these soils may have a pH of 2.5, on par with lemon juice! In such vast and rugged landscapes, these mycorrhizae also act as decomposers and, in effect, drive the ecosystem by unlocking nutrients, most of which are derived from the debris of their plant partners. As the primary decomposing and mycorrhizal fungi in their environment, these species are the master artisans of nutrient flow in these harsh habitats. However, as ERM are poorly studied, many questions about how they survive in such environments remain unanswered.

The ericoid symbiosis forms externally as a loose network of hyphae around the outside of small plant roots. From this weft of mycelium, hyphae penetrate the walls of the root's cortical cells to form intracellular *coils* that densely pack into root cells. A root may be so densely packed with coils that as much as 80% of its volume may be mycelium. The fungus provides the plant with nitrogen from proteins that the fungus has digested, and under extreme conditions the fungus may even provide the host with carbon derived from digested polysaccharides and proteins, effectively reversing one of the assumed reasons for their partnership.

In harsh habitats such as tundras, ericoid mycorrizae are central to the ecological web of the whole environment.

Arbutoid Endomycorrhizas

Many genera in the Basidiomycota.
Plants in Arbutus *(madrone),* Arctostaphylos *(manzanita), and* Comarostaphylis.

The Arbutoid relationship is mainly found with hardy evergreen shrubs and trees in the plant family Arbutoideae. Structurally, these fungi develop a thick *mantle sheath* around the outside of the cell, an extensive network of hyphae between the epidermal and cortical cells of the root (known as a *Hartig net*), and intracellular coils in the outer cortical cells of plant roots. The combination of these three features is unique to the arbutoid mycorrhiza.

The fungi involved in the arbutoid symbiosis are somewhat unique as they not only form the endomycorrhizal structures described above, but can simultaneously form very different structures (ectomycorrhizae) with plants outside of the Arbutoideae. In other words, these fungi not only form a CMN between plants of different families (like AM), they can also develop two completely different mycorrhizal structures depending on the plant they are allying with.

Monotropoid Endomycorrhizas

Several genera in the Basidiomycota, notably Tricholoma *and* Boletus.
All 10 achlorophyllous genera of the Montropaceae.

All plants in the Monotropaceae are primarily red, white, or some other non-green color due to the fact that they do not photosynthesize. Without the ability to produce sugars, these plants are largely dependent on forming a mycorrhizal symbiosis for survival. But, as fungi do not photosynthesize either, this sugar must be obtained from other plants that the mycorrhizal fungus associates with. Typically, this is gleaned from a nearby tree. As with arbutoid fungi, monotropoid species will form an ectomycorrhizal structure with this second plant. The monotropoid relationship is often described as a form of "mycoparasitism" through which the achlorophyllous plant robs the fungus—and, by extension, the second plant—of nourishment. However, monotropoid mycorrhizae may actually form a bidirectional nutrient flow, as evidenced by studies in which radiolabeled phosphorus injected into *Monotropa* plants was transmitted to surrounding trees connected through the CMN.

The monotropoid structure begins with a dense sheath of mycelium that surrounds the plant's roots. From this sheath, the fungus penetrates the epidermal root cells with a hyphal "peg." These pegs seem to be a primary source of nutrient exchange as they will swell and burst inside of the root cells, releasing cellular contents into the plant. This self-sacrifice by the fungus generally occurs from July to August, during the time of seed production in the plant.

*Non-photosynthesizing plants, such as the Ghost Pipe (*Monotropa uniflora*), are dependent on mycorrhizal fungi for their survival.*

Orchidaceous Endomycorrhizas

Several genera in the Basidiomycota (e.g. Armillaria, Mycena, and Russula).
All species in the Orchidaceae (about 880 genera with 22,000–25,000 species).

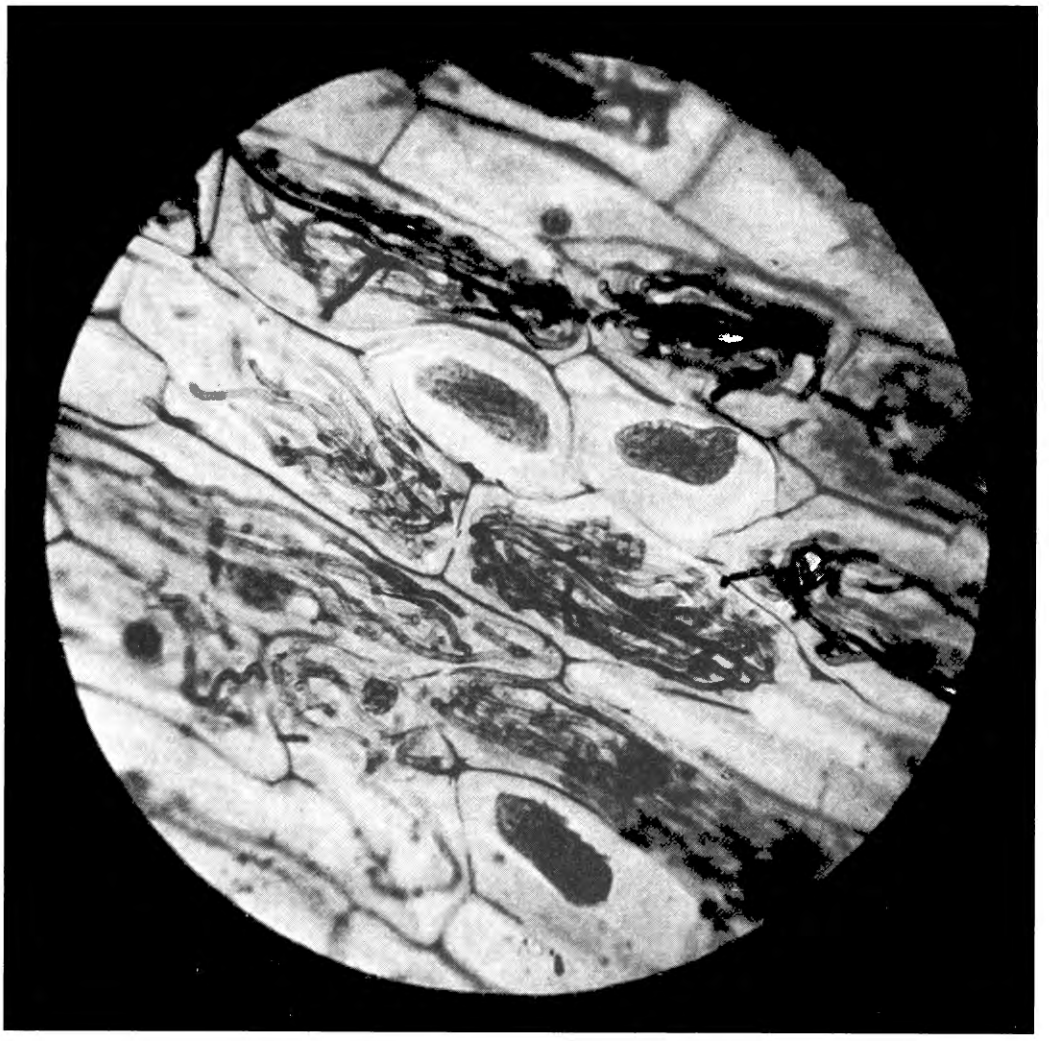
Orchids are the most complex—or "highly evolved"—of all plants, and also the largest and most diverse family of all flowering plants. Comprising approximately 10% of all seed plants, orchids outnumber birds 2:1 and mammals 4:1. Undoubtedly, this evolutionary success has occurred thanks to the complex mycorrhizal associations that all orchids form.

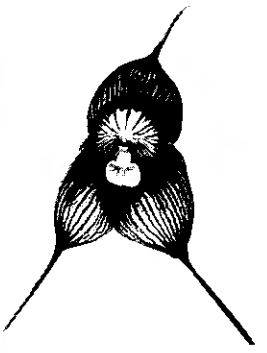
Upon hydration, the orchid seed's coat will rupture, releasing several short, root-like hairs out into the environment in search of a mycorrhizal partner. If a compatible fungus is present, its mycelium will penetrate the plant embryo where the orchid cells will invaginate the hyphal tips. Surrounded in a womb-like bubble of cytoplasm, these hyphae quickly expand into densely packed, coiled masses called *pelotons*. Like a fungal snack, peletons die a day or two after forming, at which point the orchid cell will consume the nutrient-rich hyphal nugget. Pelotons are commonly the primary nutrient source for wild orchids. Each orchid root cell can be repeatedly fed by peletons, with waves of hyphal bundles continuously developing and dissolving inside a single orchid cell. A feeding regimen may even develop between multiple fungal species, with each taking turns nourishing the same orchid root cell, much like a village raising a child.[23]

In general, orchid seedlings associate with more fungal species than mature orchids. These relationships likely change throughout the orchid's life, such as when the orchid matures and begins to produce chlorophyll. Once mature, most chlorophyllous orchids will still associate with mycorrhizal fungi to obtain nitrogen and phosphorus. Some will even extend their dependency on their mycorrhizal partner by spending several years underground before producing aerial (and photosynthetic) flowering stems. Well-known examples of this trickery are found with wild European orchids called helleborines. Once an orchid begins photosynthesizing, it may provide the fungus with carbon, contradicting the long-held belief that the relationship was not mutualistic.[24] About 200 species of orchids remain achlorophyllous when mature (e.g. *Galeola*, *Gastrodia*, *Corallorhiza*, and *Rhizanthella spp.*). *Russula* mushroom species often associate with achlorophyllous orchids.

The *Rhizoctonia* fungi that associate with many orchids are also known to act as a root rot on non-orchid plants. Curiously, these fungi do not seem to produce spores. Some *Mycena* species that associate with *Cymbidium* and *Gastrodia* orchids are better known as decomposers than as mycorrhizal fungi, a reflection of the ecological flexibility exhibited by many fungi. Seedlings of the orchid *Gastrodia elata* (a plant used in Traditional Chinese Medicine as *Tian ma*) develop mycorrhizal structures with the saprotrophic mushroom *Mycena osmundicola*, but as they mature they switch partners to the Honey Mushroom (*Armillaria spp.*), a common tree blight. *Dracula* orchids (ca. 150 species found from Mexico to Peru) produce unique landing pads in the center of their flower that look like small mushroom fruit bodies. These structures are thought to attract fungus flies that aid in the pollination of the plant; they are one of the few examples of *mycomimicry* found in non-fungal species.[25]

Most cultivated orchid seedlings are not inoculated with mycorrhizal fungi but instead are initiated on nutrient-rich media with equipment and techniques similar to those used in mushroom cultivation labs. Maturing orchids also require a humid environment similar to that needed for fruiting mushrooms. As such, I find it surprising that more orchid farmers have not picked up mushroom cultivation, and vice versa. Likely, this is due in part to a lack of perceived economic incentive. However, a study from 1998 demonstrated that Shiitake mushrooms and several other wood-rotting fungi can support the development of achlorophyllous orchids in the genus *Erythrorchis*.[26] Other such beneficial mushroom-orchid relationships have likely yet to be discovered, a promising venture suggesting numerous means for enhancing the beauty and diversity of both cultivation practices. Perhaps in the future, the combined elegance of mushroom and orchid cultivation by humans will act as a symbol of the highest collaboration between the most evolved organisms of the Plantae, Animalia, and Queendom Fungi.





(Above) Dracula *orchids have a landing pad that looks strikingly similar to the underside of a* Marasmius *mushroom cap.*

(Left) Pelotons of orchidaceous mycorrhizae inhabit and feed orchid root cells in continuous waves.

Ectomycorrhizas (ECM)

5–6,000 fungal species in 65 genera, about two-thirds are in the Basidiomycota *(e.g.* Amanita, Boletus, Cortinarius, Lecinum, Pisolithus, Rhizopogon, *and* Suillus*) and one-third are in the* Ascomycota *(e.g.* Tuber *and* Terfezia*).*
Approximately 5% of land plants (140 genera in 43 families), including about 3% of seed plants and the majority of forest trees (e.g. beech, birch, eucalypts, oak, poplar, spruce, and willow).

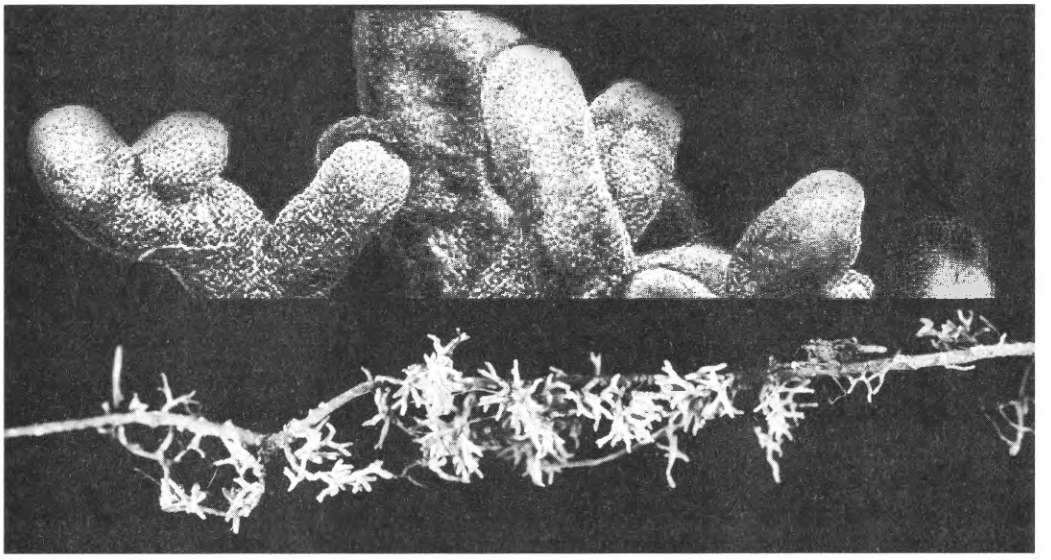
Ectomycorrhizae are considered the most advanced of all the mycorrhizal relationships, with an origin dating to approximately 250 million BCE. Many ECM fungi can be quite host specific (for example, *Boletus elegans* tends to only grow with larch trees), while others may be quite cosmopolitan (*Amanita muscaria* will associate with 20 or more tree species). Conversely, some trees may form a range of associations, such as Norway spruce (*Picea albies*), which can associate with 100 different ECM fungi at a time. The related genera *Lactarius* and *Russula* are considered some of the most important ECM species as they form mycorrhizae with many different trees around the world.

ECM fungi confer many benefits to their plant partners. For example, *Pisolithus tinctorius* and *Thelephora terrestris* are antiparasitic against the root pathogen *Phytophthora cinnamomi* on *Pinus spp. Laccaria laccata* can reduce diseases caused by *Fusarium oxysporum* in *Pseudotsuga menziesii, Picea abies,* and *P. sylvestris* trees. Some ECM species produce antibiotics (e.g. chloromycorrhiza and Mycorrhizine A) that can defend against pathogens. And *Pisolithus tinctorius* can tolerate soil

temperatures of up to 104°F (40°C), making it a choice partner for pine trees being planted in hot regions and near slag heaps. Many woodland trees will not survive without their fungal partners, leading most silviculture practices to rely heavily on ectomycorrhizal inoculum for successful outplantings.

Structurally, ECM fungi form a mantle sheath of mycelium around the roots of their plant partner that is about 5–10 hyphae deep (roughly 50–100 µm thick). This mantle is where the fungus absorbs and stores plant nutrients like nitrogen, phosphorus, potassium, and calcium. From this coating, hyphae travel into the root structure to form a dense Hartig net between the root cells. Unlike endomycorrhizal fungi, ECM do not penetrate the walls of root cells, though they may completely sheath whole cells within the root. ECM can increase the surface area of a root system by up to 47-fold.[27] Often, the resultant root tends to underdevelop and take on a short, chubby look. The plant's movement of storage sugars to its roots in the late summer and fall may be what trigger ECM mushroom formation. However, the large size of some ECM mushrooms, such as the King Bolete (*Boletus edulis*) and Matsutake (*Tricholoma matsutake*), may also be partially attributable to saprotrophic action.[28] Around 25% of ECM form underground (hypogeous) fruit bodies (e.g. truffles and their look-alikes); the other three-quarters of ECM form aboveground (epigeous) mushrooms. As noted, some ECM fungi can also form arbutoid and monotropoid associations.

ECM fungi predominate in the upper, organic-rich layers of coarser, acidic soils that receive higher levels of precipitation and where flora and fauna diversity is relatively low.[29] Where ECM diversity is high, a species gradient often extends from a forest's edge. As distance increases from the trunk line, different ECM fungi can be found occupying distinct spacial zones.[30] ECM fungi seem to be more prevalent in temperate forests than in tropical regions and in boreal forests they may account for up to 32% of the soil biomass.[31] Many of these boreal ECM may also form ericoid mycorrhizae.

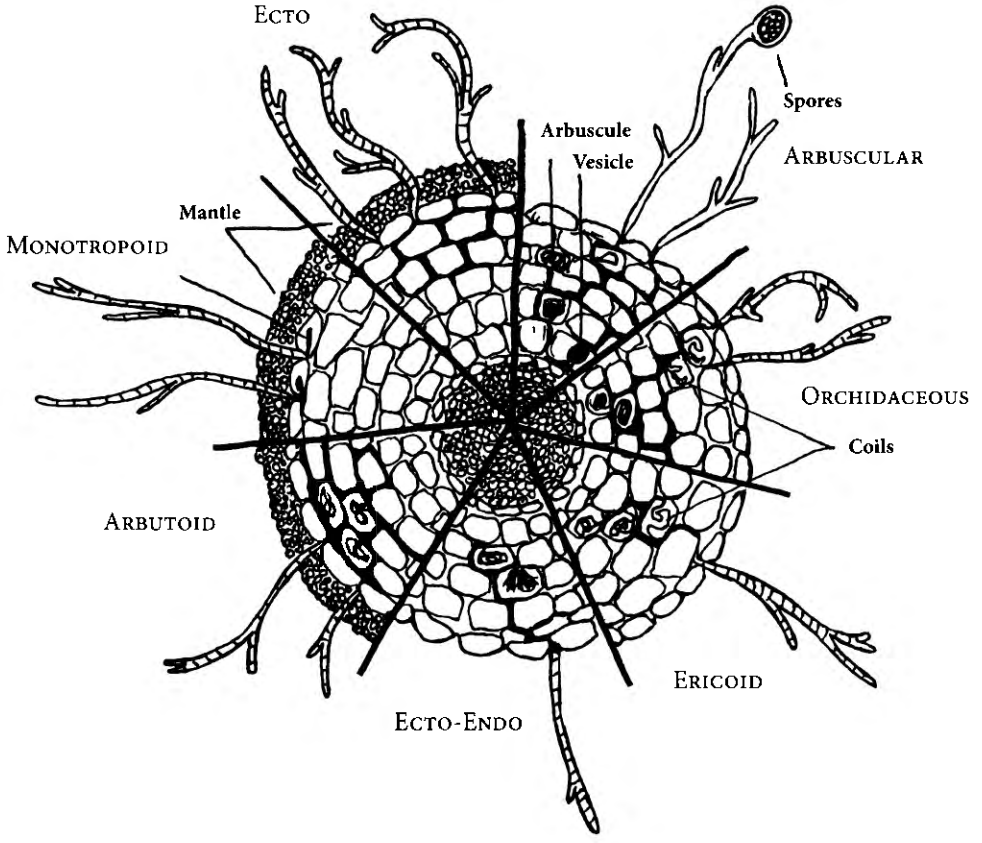


Ectomycorrhizal root tips are distinctly knubby and white.

Ecto-endomycorrhizas

Several species in the Ascomycota and Basidiomycota.
Mainly associated with trees in the genera Pinus *(pine),* Picea *(spruce), and* Larix *(larch).*

This little-studied mycorrhizal association is primarily found in nursery plants and rarely in forest ecosystems.[32] As the name implies, these fungi exhibit the same characteristics of ectomycorrhizas but will also develop extensive intracellular structures inside of the root's cells. It is possible that this dualistic relationship only develops under conditions of extreme plant stress, which the supportive fungi attempt to mediate.



Mycorhizal Forms And Features	Endo					Ecto	
	AM	Ericoid	Arbutoid	Monotropoid	Orchid	Ecto	Ecto-endo
Fungi septate		●	●	●	●	●	●
Intracellular hyphae	●	●	●	●	●		●
Mantle sheath			Y/N	●		●	Y/N
Hartig net			●	●		●	●
Vesicles	Y/N						
Plant chlorophyllous	Y/N	●	●		Y/N	●	●
Fungal Phyla	G	A	B	B	B	A, B	A, B, G
Plant taxa	An, Br, Gy, Pt	Br, Er	Er	Mo	Or	An, Gy	An, Gy

Fungi
A *– Ascomycota*
B *– Basidiomycota*
G *– Glomeromycota*

Plants
An *– Angiospermae*
Br *– Bryophyta*
Gy *– Gymnospermae*
Er *– Ericaceae*
Mo *– Monotropaceae*
Or *– Orchidaceae*
Pt *– Pteridophyta*

Nutrients, Cycled

The degree to which nutrients can readily move through an ecological system is the measure of how quickly that environment will be able to grow and respond to change. Through the actions of living organisms and the living Earth, various interconnected biogeochemical cycles endlessly move carbon, nitrogen, sulfur, phosphorus, and other essential elements throughout the world's habitats. Though all of Earth's inhabitants contribute to these nutrient cycles, the fungi are some of the most critical players in these processes for they perform some of the most complex chemical transformations required for this endless movement of the elements of life.

For example, fungi are central to the global carbon cycle. Of the 15 billion metric tons (Gt) of total fungal biomass estimated on Earth, about 5 Gt is made of carbon.[33] Much of this tissue is found in soils, where it acts a carbon reserve, or sink, for the environment and as a food source for innumerable microbes. Indeed, soils store more carbon than plant vegetation—much of this is held in fungal mycelium. Per year, fungal decomposition releases around 85 Gt of CO_2 into the atmosphere, providing nearly all of the 88 Gt needed by the world's vegetation. Much of this is released from wood, which only fungi are capable of decomposing. By comparison, human activities release around 7 Gt of CO_2 per year.[34]

This constant recycling is critical to a habitat's survival because a given element cannot be created from another element. Further, depending on the form that it comes in, a given element may or may not be easy for plants, animals, or microbes to assimilate. When chemical elements that are essential to life (e.g. nitrogen or carbon) become limited or unavailable in an environment, the organisms that depend on them will not be able to grow. As Nature's grand chemists, the fungi enable biological growth by constantly unlocking unavailable nutrients and turning them back into soluble compounds that microbes, plants, and animals can metabolize into tissue.

One of the most foundational and impressive aspects of this nutrient cycling is the fungal weathering of rocks, the study of which is known as *geomycology*. With their production of strong organic acids, fungi serve as the primary biological agents responsible for releasing nutrients from rocks into soil webs. Species from all fungal phyla are ubiquitous components of rocks around the world.[35] Fungi are found on rock surfaces (*epilithic* fungi) and in the cracks, fissures, and pores of rocks (*endolithic* species). Others are able to bore deep inside of rocks. These are the *cryptoendoliths*—those that hide inside of rock.

Fungi have been found on and inside of limestone, soapstone, marble, granite, sandstone, andesite, basalt, gneiss, dolerite, amphibolite, and quartz. *Aspergillus niger* and *Penicillium expansum* have been shown to mineralize olivine, dunite, serpentine, muscovite, feldspar, spodumene, kaolin, nepheline, and basalt, while *Penicillium simplicissimum* and *Scopulariopsis brevicaulis* can release aluminum from aluminosilicate clays.[36] ECM fungi can extract phosphorus and potassium from rocks with the use of oxalic acid.[37] And it is likely that many other fungi perform similar roles.

The oxalic acids produced by fungi to dissolve rock can also combine with calcium to form tetragonal, bipyramidal, platelike, rhombohedral, or needle-shaped calcium oxalate crystals. These crystals are important for ecosystems and soil webs as they act as a calcium sink and also increase nutrient availability by lowering the soil pH. The most common forms of calcium oxalates in Nature (e.g. weddelite and whewellite) may be produced by the oxalic acids of various fungi.[38] Fungi also precipitate carbon-containing oxalates through the interactions of oxalic acid and silicate minerals, providing an important carbon sink in terrestrial environments.

By releasing organic acids (e.g. malic, citric, and oxalic acid) and by uptaking ammonium ions (NH_4^+), mycorrhizal fungi lower soil pH, an act that releases soil nutrients like iron and phosphorus from carbonate complexes, making them available to plants. In an alkaline (high pH) environment these nutrients would otherwise remain locked into the soil matrix.[39] Mycorrhizal fungi also transform all of the 15 major macro and micronutrients necessary for plant growth (e.g. phosphorous, iron, copper, zinc, sulfur, magnesium, manganese) into forms available to plants. This is often as a simple soluble salt, which mycorrhizal fungi translocate to their plant partners through a CMN.

It hardly states the case to say that mycorrhizas are important to ecosystem function. It is much more accurate to say that mycorrhizas are ecosystem function.

—Ted St. John, Ph.D.

Mycorrhizal fungi can also obtain nutrients by decomposing animal and insect tissue. For example, *Laccaria bicolor* contributes to the late stages of decomposition of mammals and anadromous

fish, such as salmon. After these fish spawn and die on stream banks or are carried into the woods by bears, the hyphae of *L. bicolor* digest the salmon's proteins and transport the resultant nitrogen compounds to partnered tree roots. Through these and other fungi, the nutrients of the ancient oceans nourish the trees of the world. Excavations under animal remains often reveal dense mats of salvaging mycorrhizal root tips.

Laccaria species can also paralyze and consume living insects such as springtails as a source of nitrogen for plants. In one study it was found that up to 25% of the nitrogen in a *Laccaria*-associated tree's foliage came from these soil-dwelling insects.[40] Lastly, fungal exudates and the hyphae of deceased mycorrhizal fungi may serve as the primary source of carbon for whole soil microbial communities and fluorescent pseudomonads—an ecological impact that has been largely ignored by soil scientists, despite its profound significance.

Nitrogen-Fixing Fungi?

Found in DNA, vitamins, proteins, and the enzymes that fuel biological and ecological processes, nitrogen is one of the most important elements in living systems. But, being in such high demand, it is frequently also one of the most limited elements in an ecosystem. Though mycorrhizal fungi contribute to the movement of nitrogen, they cannot increase its quantity in the soil. This capacity is uniquely held by "nitrogen-fixing" microbes, which transform atmospheric nitrogen gas into compounds that are available to other organisms.

Collectively referred to as *rhizobia*, nitrogen-fixing bacteria are found in the gram-negative genera *Azorhizobium, Allorhizobium, Bradyrhizobium, Mezorhizobium, Rhizobium,* and *Sinorhizobium*. Other nitrogen-fixers include actinomycetes in the genus *Frankia*. These microbes provide a constant supply of nitrogen to their environment by either combining nitrogen with oxygen to form nitrates (NO_3^-) and nitrites (NO_2^-) or with hydrogen, making ammonium (NH_4^+).

Like mycorrhizal fungi, rhizobia are not typically found free-living in the soil. These microbes form distinct symbiotic structures on plant roots, known as *nodules*, inside of a plant membrane called a *symbiosome*.[41] Similar to the exchange of carbon for other nutrients in a mycorrhizal structure, rhizobia depend on their plant partner for their oxygen supply, which the plant provides via leghemoglobin, a substance that looks and performs very similarly to red blood cells. In exchange for this oxygen, these microbes provide their plant partner with a constant supply of nitrogen. Being only about 80 million years old, rhizobia are not nearly as widespread as mycorrhizae; they are primarily found in association with about 13,000 plants, including peas, beans, alfalfa, clover, vetch, peanuts, *Acacia*, kudzu, and red alder (*Alnus rubra*) trees.

The importance of nitrogen-fixers in plant and soil communities has been well-studied and incorporated into farming practices for centuries. However, the various influences of mycorrhizal fungi on this symbiosis have largely been underrepresented. Mycorrhizal and rhizobial symbioses often act synergistically and supportively in terms of infection rate, mineral nutrition, and plant growth. For example, AM fungi provide much of the phosphorus, copper, and zinc that are essential for nodulation and nitrogen fixation. Conversely, some bacteria can enhance the rate of phosphorus uptake in AMF and plants through the release of their own phosphatases and organic acids. Bacteria can influence AM spore germination and growth rates, thus affecting the growth of the plant that depends on the AM symbiosis.[42] There also seems to be a kind of communication between AMF and bacteria that is stimulated by fungal exudates,[43] such as the compound known as the "myc factor," which has been shown to activate rhizobia nodulation.

Together, bacteria and AMF form a beneficial biofilm in the *mycorrhizosphere*. The fungi help the plant uptake phosphorus, which in turn is provided to the rhizobia to create the nitrogenase enzyme that fixes nitrogen. In effect, more nitrogen is fixed, leading to better root growth and increased AM and rhizobia development. The fungi may also modify the structure of rhizobial bacteria along the root system and distribute the nitrogen they fix to non-rhizobia-forming plants across the ecosystem. Perhaps this is part of the reason why rhizobia are only found on some plants. Further, rhizobia in the genus *Azospirillum* have also been found to be heavily dependent on the ectomycorrhizal truffle *Rhizopogon vinicolor*, which grows at the base of Douglas-fir trees.[44]

The mycorrhizosphere effect can also stimulate the growth of beneficial fluorescent pseudomonads in soil systems.[45]

Fungi in the Age of Peak Phosphorus

Along with nitrogen, phosphorus is one of the most important plant growth-limiting nutrients in soils. As with other elements, a plant's phosphorus uptake may be entirely controlled by its mycorrhizal partner.[46] Some of this phosphorus may come from organic (carbon-containing) compounds (e.g. phytate, phosphoglucans, phospholipids, and nucleic acids), which can easily be solubilized by fungi or other microbes through the use of phosphatases and other digestive enzymes. Or it may come from an inorganic form that is bound in the soil matrix (e.g. on the surface of clay minerals) or bound with other minerals (e.g. as calcium, iron, and/or aluminum phosphates) in large, insoluble, crystalline nets. With the same acids used to desorb minerals from rock, fungi are able to unlock inorganic phosphorus from these insoluble complexes and create bioavailable phosphorus salts that plants can readily metabolize.

The production of artificial phosphorus fertilizers is, in a sense, an industrial attempt to mimic this natural fungal function, albeit one with many hidden environmental and social costs. Most notably, the mining of inorganic phosphorus rock completely destroys habitats and pollutes the environment. The processing of the rock results in significant quantities of toxic waste products, including the sodium fluoride that is added to water supplies and toothpaste. When applied in the field, the bulk of these fertilizers are subsequently lost to sea where they sink to the ocean floor and become unavilable. At current extraction rates, it is predicated that the world's rock phosphorus supplies will be extremely limited by the 2030s. The subsequent halt in phosphorus availability following "peak phosphorus" will have severe and widespread impacts on numerous ecological, agricultural, and human living systems.[47]

To help slow the arrival of this disaster scenario, rock phosphates and compost can be applied to plant root systems in concert with AM fungi and phosphorus-solubilizing bacteria (e.g. *Bacillus circulans* and *Cladosporium herbarum*).[48] Over time, these fungi and microbes slowly release the phosphorus from these mineral sources at rates required by the plant, thereby reducing fertilizer inputs and phosphate leaching. This simple strategy provides gardeners and farmers with one of the most appropriate means for creating more efficient nutrient cycling systems. It also aids in removing some of the major negative impacts currently associated with industrial food production.

Mycorrhizoremediation

Along with the elements discussed thus far, mycorrhizal fungi are known to significantly reduce the negative impacts of toxic heavy metals such as mercury, arsenic, and cesium on an environment. Heavy metals can cause a range of problems in the growth of plants, animals, and microbes and also alter soil pH, thereby reducing the availability of nitrogen, phosphorus, and potassium.

Mycorrhizal fungi perform a number of roles to mitigate these impacts and eliminate heavy metals from the soil. ECM can extract heavy metals from their substrate and concentrate these elements in their fruit body, effectively purging the soil of toxins. The oxalic acid, sidewall components (e.g. free amino, hydroxyl, carboxyl, and other groups), siderophores, and metallothionins that fungi produce can all bind (or "lock up") metals in the soil by forming complexes that keep toxins from entering plant tissues. Mycorrhizal fungi can also change a soil's pH level, influence soil microbial communities, and alter root exudation patterns, effects that additionally reduce the impacts of heavy metals.[49]

The AM-produced compounds phytochelatin and glomalin can also keep heavy metals from entering plants.[50] However, though AM fungi are common in areas polluted by mining,[51] data on the glomalin content in these and other heavy metal contaminated areas is extremely scarce. Thus, a general understanding of how these fungi influence post-mining soil communities is currently very limited. In one study, zinc-exposed AM fungi were shown to have a higher germination rate than those isolated from non-contaminated sites when later exposed to high levels of zinc.[52] This adaptation also extends to the fungus' plant partner. Mycorrhizal plants grow better and with less stress in soils contaminated by high levels of heavy metals in comparison to non-mycorrhizal plants.[53] Unfortunately, the combined influence of working with plants and fungi in heavy metal

remediation efforts has largely been overlooked due to negative precendents set by early phytoremediation studies working with non-mycorrhizal plants in the Brassicaceae and Caryophyllaceae.[54]

When heavy metal spills occur, common "treatment" strategies tend to rely on earth-moving operations that reshape and regrade the polluted environment. The contaminated soil is often removed, incinerated, and replaced with imported soil that is devoid of fungi and microbial life. This material then needs to be pH-adjusted to support plant growth. Often this is done with chemical fertilizers, which themselves may contain heavy metals. When plants are later introduced to the "restored" site as part of the remediation plan, up to 90% may fail to establish. This is likely due in part to the low population of mycorrhizal fungi and other beneficial microbes in the imported soil. Further, if the soil remains uncovered, it may dry out in the sun and become subject to the effects of weathering and erosion.

The establishment and support of mycorrhizal fungi are critical steps that are needed to fully regenerate these and other types of damaged landscapes. Not only can mycorrhizal fungi reduce the effects of heavy metals, many can also degrade toxic chemicals as they simultaneously reduce erosion and increase plant resilience. The cultivation of mycorrhizal fungi is discussed in Chapter 9 and their application in remediation strategies is covered in Chapter 10. Combined, these techniques offer a multitude of tools for enhancing the health, diversity, and resilience of whole biomes for present and future generations.

The Black Box of Soil: Deeper Insights

The dynamics of the mycorrhizosphere are perplexingly innumerable. As root hairs only live for a few hours,[55] mycorrhizal fungi must continually travel with the extending root tip to enshroud, partner with, and then peel back from rootlets as they die. From meristem to meristem, the fungi and other microbes travel with plant roots as they survey and respond to the soil web. Along the way, mycorrhizal relationships constantly climax and change as fungal species outcompete each other for root space, or the plant exchanges partners for unknown reasons.[56] As the root surges forward, this morphing mycelial wave extends in tow at a rate of 0.2–2.5 millimeters per day.[57]

Nutrient availability seems to be important in determining which mycorrhizal relationships form, as nutrient-deprived plants tend to establish mycorrhizae more readily than fertilized plants. However, mycorrhizal development is not always indicative of nutrient-poor soil. The soil type and nutrient balance as well as the plant's rooting behavior may also influence the symbiosis.[58] This is suggested by the fact that when a plant is in symbiosis with various AM fungi, there can be very different carbohydrate-phosphate exchange ratios between the various plant-fungus combinations. It is also possible that the communication and partnership between these organisms might be based on factors that are more covert and significant than mere nutrient access.

Mycorrhizal networks intimately develop over long periods of time, and yet human deeds can destroy these delicate relationships in a misguided instant. Soil tillage can fragment mycorrhizal networks and turn mycorrhizal spores deep into the soil where they are not normally found, limiting their survival. Over-fertilized plants may be discouraged from forming mycorrhizal symbioses, leading to a loss in AM diversity. If unabated, such practices can lead to the loss of mycorrhizal diversity and abundance as well the dissolution of soil glomalin, leading to a subsequent decrease in soil porosity and vitality. If a protective plant cover is removed from such deprived environments (e.g. by clear cutting trees or planting monocrops of low vegetation), the moist soil that was once shaded will quickly dry and die in the sun until it erodes or blows away. In the end, a once-fertile landscape will be left barren with no topsoil to sustain future plant growth, while aquatic life in downhill water systems will be choked out by soil sediment as it washes out to sea.

A striking combination of these effects occurred in the U.S. during the early part of the 20th century. In the great Dust Bowl of the Depression era, farmers were devastated to find that, after decades of working the vast plains across the Mid West, the soil beneath their feet was drying up and blowing away. Though not commonly recognized, this tragic episode in American history is largely attributable to the destruction of the mycorrhizal communities that had spent centuries building the rich soil the farmers once praised. As the soil was continuously depleted over de-

cades, these precious fungi died, and the ground was turned from soil to the dust that eventually uplifted into massive clouds and stormed across the world for years.

Though the Dust Bowl occurred less than a century ago, its lessons seem to have largely been forgotten by land managers. Industrial agricultural practices, resource extraction, and the clear cutting of forested areas are common practices that are known to destroy soil systems. When trees are removed en masse from an environment, the significant nutrient loss and compaction that results can eliminate the ECM fungi, microbes, and soil yeasts that are critical for nutrient cycling and supporting plant and animal life.[59] The result is inevitably a severe imbalance in the ecosystem. When dynamic forests are clear-cut, they are often replaced with singular tree species. In these unnatural environments, invasive non-mycorrhizal plants can readily establish in the single-age understory, increasing competition while depleting the soil. In the long run, the soil may become unstable and erode, leading to a critical loss of nutrients and biodiversity. To ensure that tree stocks are retained, fertilizer and pesticide application may be increased, further reducing the formation of mycorrhizal associations in the short and long term.

Though tree plantations are usually inoculated with mycorrhizal fungi out of necessity—the trees would not establish otherwise—this mutualism cannot be claimed to replace the complex relationships in the mycorrhizosphere that take centuries to establish.[60] In areas that are constantly logged, any degree of succession is essentially impossible. Succession is not found in stages but in a gradual change over time and space. Successional waves of ECM mushrooms have been described during the development of temperate forests, particularly those of *Betula, Pinus* and *Picea* trees. Such alterations in mycorrhizal species diversity may take up to 41 years to stabilize.[61] Further, as no two forested areas ever recover from an impact in exactly the same manner, it is difficult to anticipate how a given landscape will respond to an impact, let alone how to mitigate any negative consequences thereafter.

All told, these and other fungal influences on the world's nutrient cycles and habitat communities must be incorporated into any ecological study and used to refine current models of how ecosystems develop and respond to change. To create the most resilient soil, plant, and human communities, the incredibly complex and delicate mycorrhizosphere must be acknowledged, protected, and studied for its central role in the creation of regenerative living systems and in the preservation of the remaining wild spaces on Earth.[62]

The Mycobiome

Moving out of the soil matrix, one finds fungi permeating the interior of nearly all aboveground organisms. Though commonly presented to be isolated, sterile individuals, all plants and animals are more like unique ecosystems filled with complex communities of fungi, bacteria, and other organisms. As elsewhere, the fungi involved in these dynamics play an integral role in enhancing the health of the larger body and in reflecting conditions of the external environment. However, the mysterious nature of these hidden dynamics are only just beginning to be unraveled, with the following being the few relationships that are best understood.

Endophytic Fungi

Permeating the entirety of nearly all plant tissues are the ubiquitous endophytic fungi. Though some of these fungi are considered parasites when free-living, when cohabitating inside of a plant they generally produce no symptoms or discernable negative influence. They are most often observed in aboveground plant tissues, but there are some root-dwelling endophytes that perform functions similar to mycorrhizal fungi. Endophytes include members of the Dothideomycetes, Sordariomycetes, Leotiomycetes, Eurotiomycetes, and Pezizomycetes. Agaricales are common endophytes in grasses, while species in the Russulales, Polyporales, and Agaricales are common in woody tissues and roots.

Endophytes associate with all major land plant lineages, including liverworts, hornworts, mosses, lycophytes, equisetopsids, ferns, and seed plants (angiosperms). They range from the Arctic to the tropics and occur in agricultural fields and throughout the wild. Those found in marine plants, such as algae, have been shown in recent years to produce unprecedented bioactive compounds that deserve far more investigation.[63]

Conservative estimates suggest that at least 95% of all plants in the world live symbiotically with endophytic fungi. The ubiquity of this association is likely due to plants co-evolving with these fungi for at least 400 million years.[64] Since the first endophytes were described in 1904,[65] the research that has accumulated over the last century now suggests that most plants in natural ecosystems, if not all, are symbiotic with at least one, if not hundreds of thousands, of endophytic and/or mycorrhizal fungi. A single Douglas-fir tree has been conservatively estimated to host up to 100,000,000,000 individuals of the endophytic fungus *Rhabdocline parkeri*.[66] In essence, every plant must be seen as a unique quilt of species sewn together by the threads of enigmatic hyphae. These hidden fungi are everywhere, performing unknown acts and intimately communicating with their plant partner and potentially other fungi in ways that are not understood. Like mycorrhizal fungi, endophytes seem to be an intrinsic component of plant survival strategies. And yet, despite their vast spread and seemingly profound ecological importance, they remain in one of the least studied of all fungal niches.

From what is known, endophytes seem to increase productivity, succession, diversity, and energy flow through the plants they inhabit and, by extension, their environment. Some endophytes also fiercely respond to attacks on their plant partner. For example, when cynipid wasps (gall wasps) lay eggs in a plant (commonly oaks), the plant's asymptomatic endophytic fungi can suddenly come out of hiding and infect the galls that these insects create in the plant as a food source for the larvae. Subsequently, the larvae will die from a lack of food, after which point the endophyte will return to hiding and become asymptomatic.[67]

In a sort of cleansing role, if the plant is subjected to stress its endophytes may alter their function and become parasitic,[68] thereby killing their plant partner. Though this may seem negative in the short-term, such purging may ultimately serve to benefit the long-term health of the environment (e.g. by mitigating the spread of other pathogens). In other words, as endophytes fill the entirety of the plant world, they watch over the forests, fields, and oceans, fine-tuning its health, and directing the flow of vital energy throughout their environment, pushing the whole of life forward in the process.

Some endophytes may also express multiple life cycles, such as living primarily as asymp-

tomatic mycelium and then, under certain conditions, forming a teleomorph that can form fruit bodies. Such a hypothesis has been proposed for *Psilocybe cyanescens*, a psychoactive mushroom that is rarely found in the wild but primarily in piles of alder woodchips. As further discussed in Chapter 7, endophytic fungi may also be directly responsible for the production of the medicinal compounds in plants, a prospect with significant historical and cultural implications. The following are the four classes of endophytic fungi that are currently recognized.[69]

Clavicipitaceous *(C-endophytes/Class 1/C-1)*

Ascomycota (class Clavicipitaceae, order Hypocreales, telemorphic genera Epichloë *and* Balansia*, anamorphic genera* Neotyphodium *and* Ephelis*, respectively).*

Commonly found in most grasses and cereal crops, the agricultural significance of Class 1 has brought these endophytes the most attention. In general, plants usually host one dominant C-1 species. C-1 fungi tend to be transmitted to seedlings by travelling *inside* of the seeds of plants, making them intimately connected to whole plant lineages. C-1 species can also be found free-living, filling non-endophytic niches as symbionts (e.g. *Cordyceps* species), pathogens (e.g. ergot [*Claviceps purpurea*]), and/or saprotrophs. Some entomopathogenic fungi (e.g. insect-attacking *Beauveria bassiana*) are currently being investigated for their potential as endophytic inoculum for plants.

C-1 endophytes provide a range of benefits to plants such as increasing plant biomass, conferring drought tolerance and disease resistance, and producing chemicals that are toxic to animals, thereby decreasing herbivory.[70] However, the degree of benefit provided by the fungus appears to depend on the plant species and genotype as well as environmental conditions. It is unknown whether the disease resistance is attributable to the fungus, plant compounds produced in response to the endophyte, competition between fungi, or some physical exclusion mechanism.

C-1 endophytes also produce a range of bioactive substances. *Neotyphodium tembladerae* infects several species of South American grasses, making them toxic to mammals.[71] The dronk gras (*Melica decumbens*) of South Africa and the drunken horse grass (*Achnatherum inebrians*) of Asia (which is infected by *Neotyphodium gansuense*) are both avoided by animals.[72] In 1977, the *Acremonium* endophytes in sleepy grass (*Achnatherum robustum* or *Stipa robusta*) were found to produce lysergic acid amine, a precursor to the psychoactive compound LSD.

Nonclavicipitaceous *(NC endophytes/Classes 2, 3, and 4)*

NC endophytes have been recovered from every major lineage of land plants (e.g. nonvascular plants, ferns, conifers, and angiosperms), and from all terrestrial ecosystems, including agriculture systems and biomes from the tropics to the tundra. Compared to C-1 endophytes, relatively few studies have been conducted with these fungi. NC endophytes are subdivided into three groups:

Class 2 NC

Mostly Ascomycota and a few Basidiomycota.

These fungi are found in the roots, leaves, and stems of plants. They are capable of growing through a large amount of the plant tissue, though their diversity in an individual plant is often quite limited. They are transmitted between plants by spores (horizontally) and via seed coats, seeds, or rhizomes (vertically).

A unique aspect of Class 2 endophytes is their ability to confer habitat-specific stress tolerance to plants.[73] They have been shown to increase plant tolerance to drought, desiccation, heat, and salinity, and to increase a plant's root and shoot biomass. In one study, endophytes removed from grasses growing in geothermal soils near Lassen Volcanic and Yellowstone National Parks were shown to provide thermoprotection to tomato, watermelon, and wheat plants planted in 149°F (65°C) soil for ten days.[74] When grown nonsymbiotically, neither the fungus nor the plant it was cultured from could tolerate temperatures above 104°F (40°C): the symbiosis was required to enable both partners to tolerate such extreme temperatures.

Class 3 NC

Ascomycota and Basidiomycota.

Class 3 endophytes only grow in the aboveground tissue of plants, including non-vascular plants, seedless vascular plants, conifers, and angiosperms. They are found in the flowers, fruits, wood, and bark of these plants and are spread by sexual or asexual spores. All land plants studied to date contain these fungi.[75] Class 3 endophytes tend to form highly localized mycelium, allowing for a high degree of Class 3 diversity in a single plant. An individual plant leaf may harbor one fungus per 2 mm^2 of leaf tissue.[76] Different leaves on the same tree may have quite distinctive assemblages of dozens of endophytic fungi,[77] while whole plants may harbor hundreds of different species. Across its native range, a given plant species may form symbioses with thousands of endophytic fungal species. Class 3 species are found around the world, from tropical forests to boreal and Arctic/Antarctic ecosystems. Fungi similar to Class 3 endophytes are also found in lichens and are known as *endolichenic* fungi. Despite such wide distribution patterns and likely high ecological importance, the role of these fungi is essentially unknown.

Class 3 endophytes include many fungi in the Pezizomycotina (e.g. species in the Pezizomycetes, Leotiomycetes, Eurotiomycetes, and especially the endophyte-rich Sordariomycetes and Dothideomycetes) as well as some Saccharomycotina.[78] Several plant pathogens and saprotrophs in the Ascomycota are also derived from these lineages.[79] Endophyte specificity can differ markedly by biome and plant lineages. For example, conifers tend to host endophytes from the Leotiomycetes, while tropical plants often partner with endophytic Sordariomycetes. In general, seedlings that are grown under sterile conditions do not contain culturable Class 3 endophytes.

Class 4 NC

Ascomycetes that are conidial or sterile (including taxa in the orders Xylariales, Pezizales, Elaphomycetales, Onygenales, and Saccharomycetales).

These endophytes are restricted to plant roots where they form extensive networks of hyphae containing distinct, darkly melanized septae. These "dark septate endophytes" (DSEs) do not form mycorrhizal structures, but they do tend to lack host or habitat specificity, similar to the distribution of arbuscular mycorrhizal fungi. DSEs are found worldwide in African coastal plains and lowlands, some tropical ecosystems, and most alpine, sub-alpine, temperate, Antarctic, and Arctic zones.[80] They are commonly found in boreal and temperate forests as well as high-stress and nutrient-limited environments, suggesting they may enable plant establishment and survival in these areas. DSEs seem to have low geographic or host specificity. For example, *Phialocephala fortinii* associates with plants from the Pinaceae, Cyperaceae, Ericaceae, Salicaceae, and Rosaceae families. Other DSEs associate with plants in the Angiospermae and Gymnospermae, including plants that are non-mycorrhizal, as well as with plants with known arbuscular, ericoid, orchid, and ectomycorrhizal associations. In alpine and semi-arid ecosystems, DSEs can be more abundant than AM fungi.[81]

Due to limited research, Class 4 endophytes have only been reported in around 600 plants. DSEs are found in association with the fine roots of shrubs and trees, especially conifers. They can also share root space with AM and ectomycorrhizae in trees from the Pinaceae.[82] Such dynamics may be common in other genera of plants, though DSE diversity within individual plants has, in general, not been sufficiently evaluated. Unlike AM fungi, DSEs can form mutualistic symbioses with the roots of plants in the Brassicaceae.[83]

DSEs form four main physiological structures in plant roots. Runner hyphae appear as individual, superficial fungal strands following the depressions between epidermal root cells. Swollen appressorium appear prior to penetrating a host cell wall. Thin penetration tubes enter the cell wall and microsclerotia develop as rounded, intracellular clusters of thick-walled hyphae. Some DSEs form mycorrhiza-like structures. When used to inoculate the orchid *Dendrobium nobile*, one DSE was shown to form structures similar to pelotons and to increase the plant's height, biomass, and stem diameter.[84] DSEs in general function similarly to mycorrhizal fungi, yet in many mycorrhizal studies, DSEs are ignored or reported as contaminants.

These endophytes seem to confer various benefits to their plant partner, including an increase

The Fungi of Antarctica

With only two vascular flowering plant species on the entire continent of Antarctica (*Deschampsia antarctica* and *Colobanthus quitensis*), the 484 lichen species and countless cryptic fungal species on the continent demonstrate the resilience of the Queendom. Even in these two plants—which live in thin soils made of gravel or acidic organic residues—dozens of endophytic species persist, including DSEs.[89] These include species from *Alternaria, Aspergillus, Cadophora, Davidiella, Entrophospora, Fusarium, Geomyces, Microdochium, Mycocentrospora,* and *Phaeosphaeria.*[90]

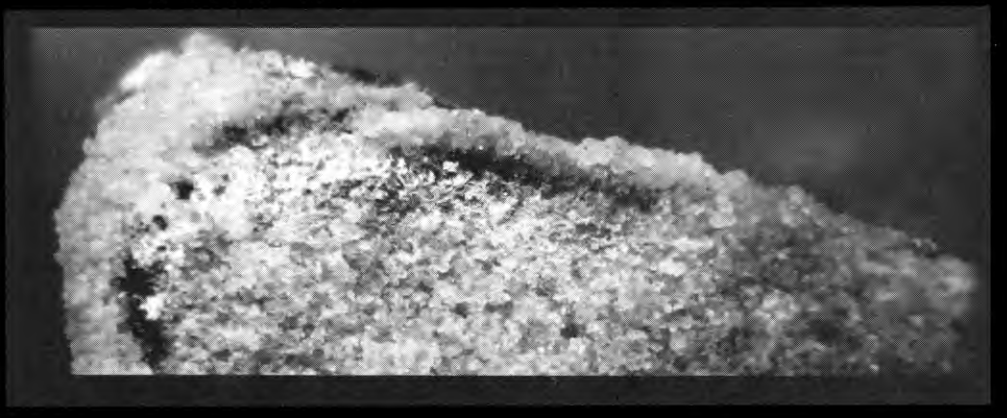
Most of the continent's other fungi do not live exposed to the elements, but find shelter as cryptoendoliths inside of translucent rock—primarily sandstone. Many of these stone dwellers are found in the high elevation of the Antarctic Dry Valleys of the continent, the coldest and driest region on Earth. Only the most resilient extremophilic (psychrophilic) organisms are capable of surviving the extreme cold, aridity, high UV radiation, and constant wind disturbance of this area. Though some of the fungi and bacteria here are free-living, most only live in lichen, or lichen-like, communities. These are the most widespread forms of symbiosis in the Antarctic Dry Valleys.

As shown below, about one millimeter below the rock surface, a layer of free-living black fungi creates a shield that filters harmful UV light from the rock's inner community of black and/or white lichenizing fungi and photosynthetic cyanobacteria and/or algae below. Many of these fungi release inorganic nutrients such as iron from the rock, an essential role in the community's nutrient-poor niche. The rock's community may be up to 0.4 inches (10 mm) deep. Including these lichen communities, there are at least five distinct types of these cryptoendolithic communities on the continent, each defined by their known phototrophic member (photobiont). They include:

- Lichen-dominated communities (most prevalent) that have algae from the genera *Trebouxia, Pseudotrebouxia, Hemichloris,* and the cyanobacteria *Chroococcidiopsis.*
- The cyanobacterium *Chroococcidiopsis.*
- The cyanobacterium *Gloeocapsa.*
- The cyanobacterium *Hormathonema-Gloeocapsa.*
- The algae *Hemichloris.*

Representative Antarctic cryptoendolithic fungi include:

- *Cryptococcus friedmannii.*
- Lichen-forming *Texosporium.*
- *Rhodotorula* species, which have been cultivated at 14°F (-10°C).
- Species from the genera *Friedmanniomyces* and *Cryomyces.* These "black yeast fungi" create the black layer in cryptoendolithic communities. They also belong to the Ascomycota class Dothideomycetes, which contains many polyextremophillic and stress-tolerant fungi, and is by far the largest and arguably most diverse class within the largest fungal phylum.[91]
- Species from the order Chaetothyriales are dominant mycobionts of cryptoendolithic lichens. These resilient fungi are not only desiccation and UV resistant, they are also found in hot desert environments. Some of these fungi have been cultured and guided to form lichens in the lab.



in root, shoot, and biomass by up to 122%[85] and increased acidity tolerance.[86] They may also act as saprotrophs in some instances to provide nutrients to their plant partner.[87] In arid ecosystems, DSEs in the order Pleosporales are commonly found in both rhizosphere soils and in biological soil crust communities (discussed in Chapter 5). This wide range suggests that DSEs may significantly increase nutrient access for plants in harsh environments by linking plant roots to the biological soil crusts that fix carbon and nitrogen (a concept known as the *Fungal Loop Hypothesis*[88]). And yet, after almost a century since their initial discovery, the ecological role of the ubiquitous and seemingly critical dark septate fungi (including their influence on plant biology and ecophysiology) remains largely unknown.

Animal-Fungal Relations

Compared to the fungi inside of plants, only a few fungal-animal relationships have been studied in depth. From what is known, it seems that fungal endosymbionts inhabit the guts of many animals, where they help digest and detoxify food.

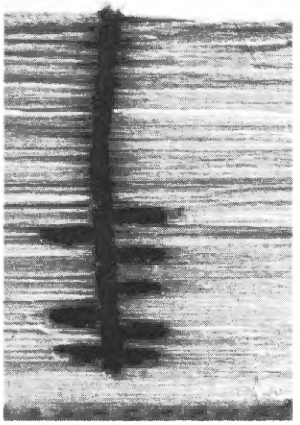
The bodies of insects seem especially replete with an "extraordinarily widespread and fantastically complex"[92] assembly of yeasts (primarily *Saccharomycetes spp.*) and "yeast-like endosymbionts" (YLSs) that seem more closely related to filamentous Ascomycetes than true yeasts.[93] This relationship dates back at least 420 million years, as evidenced by spores inside fossilized bug scat. Today, the relationship is so intimate that some YLSs, such as those in planthoppers, are never found free-living but are only transmitted to the insect's offspring through its ovary. Despite their seeming ubiquity inside of insects, fungal endosymbionts have been essentially ignored since entomologists first discovered them nearly 100 years ago.

Beetles and Yeasts

The largest order of insects in the world is the Coleoptera—the beetle clan. Comprising over 350,000 species that are found in nearly all habitats and consuming nearly any food source, beetles are among the most evolutionarily successful insects in the world.

The robust digestive capacity of beetles is likely to be attributed to the hyperdiverse abundance of yeasts that inhabit the guts of these insects. It seems that all beetles contain dozens or hundreds of yeast species in their guts, some of which may descend from yeast lineages that are not encountered in other habitats (e.g. the *Candida tanzawaensis* clade). In a study from 2005, over 200 undescribed yeast species were found in the guts of beetles, representing over 30% of the known yeast species in the world.[94] Such revelations suggest that current estimates of yeast species diversity may be significantly low.[95]

Taking their relationship with fungi one step further, ambrosia beetles (ca. 3,000 species) excavate tunnels (or "galleries") inside of dead wood, where they cultivate fungal gardens of yeasts and wood-decaying mycelium as their sole food source. Considering that this symbiosis has arisen multiple times in the evolution of beetles, it is a strong example of convergent evolution. Similar practices are observed between wood wasps from the Xiphydriidae and various Ascomycetes (e.g. *Daldinia decipiens* and *Entonaema cinnabarina*).



(Above) This Death Watch beetle may be host to dozens of undescribed yeast species.

(Below) Ambosia beetle galleries are miniature fungal farms that feed maturing larvae.

The Gastronomic Chytrids

Like humans, most animals cannot digest the cellulose that makes up plant cell walls. However, rather than passing cellulose through their gut (as humans do in the form of "dietary fiber"), many herbivores are reliant on Chytrids in their guts to digest the plant material they consume.

The intimacy of this relationship is most apparent in cows. When a cow swallows grass or other plant matter, the material first enters the initial three stomachs of the animal (the rumen, reticulum, and omasum). These stomachs are essentially fermentation tanks in which small ponds of Chytrids digest the plant matter, forming cud. This cud is then regurgitated into the cow's mouth where it is further chewed and then swallowed a second time to enter the animal's true stomach (the abomasum), which is the only site that produces endogenous digestive enzymes (pepsin and rennin) and acid. The abomasum makes up about 80% of the total stomach volume in calves, while

in mature cows it only fills a mere 10%. Thus, as the cow ages and become less dependent on milk, it becomes increasingly reliant on its internal Chytrids to survive.

Similar Chytrid-dependent relationships are found in over 50 animals. These include herbivorous reptiles and various ruminant and non-ruminant mammals such as sheep, goats, deer, giraffes, llamas, antelope, elephants, horses, and likely many large herbivores. This relationship may be as ancient as the lineages from which these animals descend. Thus, the rise of one of the central pillars of omnivorous human cultures—animal husbandry—is an art that has been entirely and secretly dependent on micro fungi to flourish. Without these micro fungi, many cultures, customs, and cuisines of today would look entirely different, potentially with an increased emphasis on eating mushrooms as a source of protein and other nutrients.

The Mycobiota of the Human Mycobiome

As with many other animals, our own digestive tract is highly dependent on an internal microbial community that aids in the digestion and assimilation of nutrients. The composition of this microbiome in the gut is often emphasized for its diversity of bacterial species, such as those in the genera *Lactobacillus* and *Bifidobacterium*. In comparison, the dynamics and impacts of the gut's *mycobiome* has remained poorly understood since first being noted for its role in digestion nearly two decades ago.[96]

Among the limited studies available, one report from 2013 demonstrated that the population and diversity of human gut fungi can vary widely, often in relation to diet. In the study, 66 distinct genera were found amongst the participants sampled, including *Aspergillus, Candida, Claviceps, Cryptococcus, Fusarium, Penicillium,* and *Saccharomyces*, along with many other unidentifiable taxa. *Saccharomyces* was by far the most prominent genus. High populations of *Candida* were positively correlated with the consumption of carbohydrates, while their low occurrence related to diets high in proteins and fatty acids. Interestingly, samples tended to predominate in either species from the Ascomycota or Basiodiomycota, but rarely in an even mix of the two.[97] It has also been suggested that alterations of the gut mycobiome may be a means to address obesity.[98] Thus the question we must all ask is, "Is my gut asco or basidio friendly?"

Beyond the intestinal tract, fungi permeate the human body. The lungs contain their own array of fungal symbionts, as does the birth canal. In one study of the vaginal mycobiome, 16 different species of *Candida* were found along with various Ascomycota (*Davidiellaceae, Cladosporium, Eurotium,* and *Alternaria spp.*), Basidomycota (*Rhodotorula spp.*), and many unclassified fungal species. Is it quite likely that these fungi enter the mouths of babies during birth, helping initiate the development of the beneficial mycoflora in their mouths and bodies that assists in their growth and protection.[99]

Successional Enforcers: Lessons from the Vocal Fungi

As plants and animals grow into their latter years or become struck with an inopportune assault, they may find themselves gradually or suddenly overtaken by the great fungal instigators of change and cleansers of disease: those that consume the living tissue of other organisms. Though ever present in the air we breathe and the soil beneath our feet, these fungi only tend to arise and forcefully alter their environment when suitable conditions present themselves. This might be when the fungus enters the warm, moist interior of an otherwise healthy plant or animal or, most commonly, when an imbalance presents itself in an organism or in an ecosystem at large.

Whereas most other fungi subtly guide succession in a habitat through the movement of nutrients and the formation of symbioses, vocal fungi are more visible in their effect. They are the heavy-handed healers of Earth, strictly enforcing a code of optimal hygiene and constant diversity. They are the creators of morphogenic designs and the increased complexity that results in the heightened resilience of otherwise tenuous arrangements amongst plants, animals, and microbes.

Generally, these aggressive fungi only appear in small, confined areas. And, as mycologist Nicolas Money presents in the book *The Triumph of the Fungi,* essentially all of the major fungal blights of history have human influence to blame. The artificial and unnatural niches that humans have

crafted have been favorable to the spread of these fungi. Sometimes, blights are directly attributed to the importation of plants that are not adapted to the fungal forces in their new environment. The monocropping of singular plant species is an unnatural practice that is especially susceptible to blight. Monocrops produce a lack of diversity and a subsequent opening in the habitat, a niche through which fungi can enter, cause a disturbance, and ultimately help reset the scales on the local plant population. The pattern is clear: where natural diversity lacks, vocal fungi prevail.

In other instances, the proliferation of aggressive fungi may be attributable to the fact that humans no longer steward and tend the wild as many Indigenous societies have for generations. Prior to and during the colonization of North America by Europeans, Native American and First Nations peoples regularly burned vast areas of land as a means to manage and increase the productivity of wild crops—including mushrooms—while simultaneously reducing the impacts of invasive and diseased plants.[100] Just as we have evolved to depend on other organisms for nourishment, so have plants, animals, fungi, and the wild at large developed the need for humans to support their habitats and dynamics. When this stewardship is not provided, imbalances arise and yields are reduced. Indeed, some Native American tribes still assert that mushroom yields will increase if the fungus is picked.[101] Similarly, domesticated plants may lack the protective endophytic diversity found in wild plants, a hidden factor that may underlie the proliferation of many fungal infections in large-scale agriculture practices.

In essence, vocal fungi provide "checks and balances" in an ecosystem, helping to manage the diversity and population of organisms in complex ways that humans have barely begun to understand. These fungi clear areas of overgrowth, opening up the tree canopy to allow light to enter the understory. They create the hollow snags that provide refuge for mammals, birds, and insects. Ultimately, they ensure that no habitat remains static for long, thereby propelling succession and increasing the structural, compositional, and functional diversity of an ecosystem that is vital to its overall resilience. Further, it is also possible that to some degree the host plant allows itself to be altered or killed, a self-sacrifice of sorts that may ultimately work for the benefit of the fungus in the short-term, but will enhance the plant's seedlings and habitat in the long-term. Whereas other fungi support the immediate life of individuals, the vocal species tend to the positive growth of a habitat over the long term.

Unfortunately, modern humans have largely misinterpreted this role of the vocal fungi. Today, many land managers uphold unsustainable practices in an attempt to address the complexity of designing ecologically sound, broad scale agricultural and forest management practices. Often these practices, such as the use of toxic pesticides, are excused by the scapegoat of these forceful fungi. In effect, as farmers and forest managers work to fight fungi, they ignore the ecological importance that these species hold, leading to greater dependency on their unnatural and faulty practices.

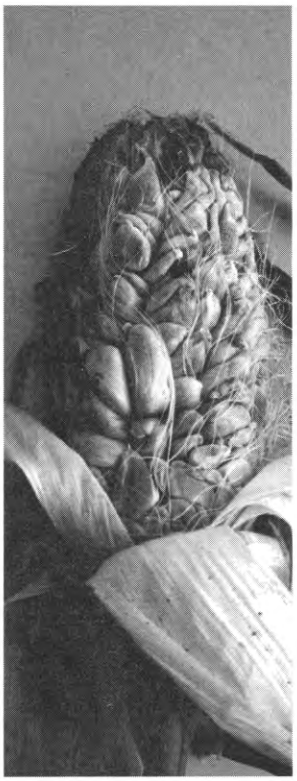
Vocal fungi help push humans into the wild, to interact with and learn from these acts of clearing and cleansing. Perhaps earlier societies mimicked these purging patterns in their tending of their environment, recognizing them as calls for increased stewardship and attention to the great cycles. Today, through the lessons of these fungi, we can also return to a new relationship with the forests and untouched wild spaces to remember the value in releasing the life of others on to the wisdom of Nature's demands in the endless process of evolution.

Biotrophs

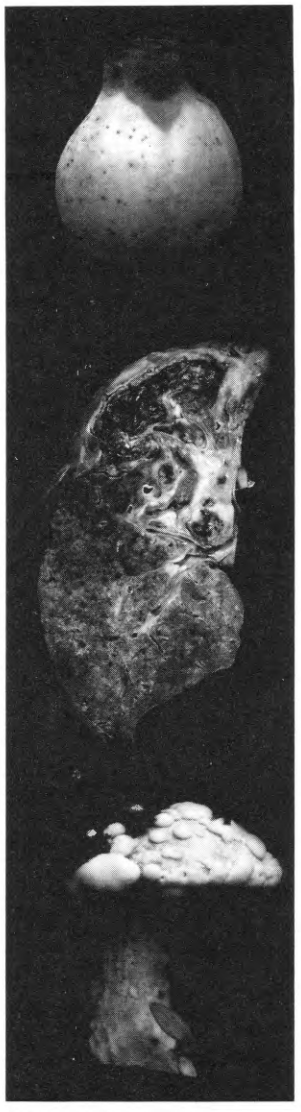
The biotrophic vocal fungi feed on the living tissue of organisms but do not kill their host. They are often obligate parasites.

Smuts *(ca. 1,000 species in the Ustilaginales of the Basidiomycota).*

Generally asymptomatic until the host plant's fruiting season, these fungi replace some of the plant's fruits with diploid *teliospores*. Most specialize on cereal crops. Huitlacoche (*Ustilago maydis*) replaces kernels in corn and teosinte species (*Zea spp.*) with savory masses that are eaten as a delicacy in Mexico. Some people intentionally cultivate Huitlacoche by inoculating corn silks with the spores of the fungus. Others seek out infected cobs that are discarded from cornfields.



*Huitlacoche (*Ustilago maydis*) is a smut that commonly infects corn. It is also a delicious, umami-rich delicacy cherished in Mexico.*



Fungi infect and digest many substrates.

(Top) A Phoma *species attacking a papaya stem.*

(Center) Aspergilloma (mycetoma or "fungus balls") filling a human lung.

(Bottom) Hypomyces chrysospermus *attacking a* Boletus *species.*

FIND THE HUMUNGOUS FUNGUS

44° 28' 34.21" N
118° 29' 5.17" W

***Rusts** (ca. 7,000 species [168 genera] in the Uredinales of the Basidiomycota).*

Named after their rust-colored *uredospores*, these diverse fungi often require multiple plant hosts to complete their highly complex lifecycle. *Puccinia* and *Uromyces* are common genera; they tend to be generalists, whereas most other rusts specialize. A single rust species may create five morphologically distinct spore-producing structures to complete its life cycle (e.g. spermagonia, aecia, uredinia, telia, and basidia). Often these various structures must form on different plants. Thus, removing one of these plants in the cycle from an area influenced by these fungi can help mitigate the fungus' spread.

Colorado Rust (*Puccinia monoica*) infects Fendler's Rockcress (*Boechera fendleri*) and causes the plant to produce leaf clusters that look like flowers (psuedoflowers). From these structures, the fungus emits a sugary solution that smells like nectar and has a similar visible and ultraviolet light output as that of the flowers it replaces. This subsequently attracts the plant's normal pollinator insects to the fungus, thereby increasing the spread of spores between infected plants and increasing hyphal mating.

***Powdery Mildew** (ca. 100 species in the Erysiphales of the Ascomycota).*

Commonly seen in vegetable gardens, these fungi produce white pustules on plants leaves and fruit surfaces. Most are host-specific and produce spores in cleistothecia.

***Downy Mildew** (not true fungi, Oomycota).*

Downy mildews rob nutrients from plant cells, especially vine plants. The genus *Phytophthora* ("plant destroyer") is notable for its 100+ species that infect a variety of crops. Most downy mildews are considered hemibiotrophic, as they tend to start out as biotrophs that eventually kill their plant host. Developed in the 1870s, the Bordeaux mixture was the first chemical used to control a plant disease. It is still used on downy mildews in vineyards.

NECROTROPHS

These vocal fungi are the most closely associated with death as they invade and ultimately kill living organisms. Many are quite virulent but often only present in unnatural or unhealthy systems. Necrotrophic fungi include the most infamous blights of history, including white pine blister rust, chestnut blight, sudden oak death (*Ramorum spp.*), and Dutch elm disease, which wiped out 700,000 trees in only a few years after its introduction to the U.S. in the early 1900s. All of these fungi were introduced from abroad.

In the Malheur National Forest in eastern Oregon, an ancient mycelial network of *Armillaria solidipes* covers roughly 3.4 square miles (8.4 km^2), or about three times the size of Central Park in New York City. At 1,900–8,650 years old, this "humungous fungus"[102] is the largest organism in the world. And it is also a necrotroph that girdles and kills many commercially cultivated trees, including timber crops of Douglas-fir and western hemlock (*Tsuga heterophylla*).

Seed(ling) Cullers

Often called "damping off" disease, these fungi are common in soil systems but tend to only infect plants that are stressed by drought, poor light, nutrient deficiency, or insect damage. They may be generalists or host-specific, and they are attracted to plant exudates released by seeds and seedlings.

Athelia rolfsii is a seedling pathogen in warm, seasonally wet parts of the world. Its sclerotia survive through the dry season and germinate after the first rain to kill seedlings. Crater disease (*Rhizoctonia solani*) forms bead-like masses of hyphae on roots that stunt seedling growth. This rather tenacious leveler of monocrops causes sugar beet root rot, cucumber belly rot, bare patch of cereals, sheath blight of rice, and black scurf on potatoes.

Vascular Wilts

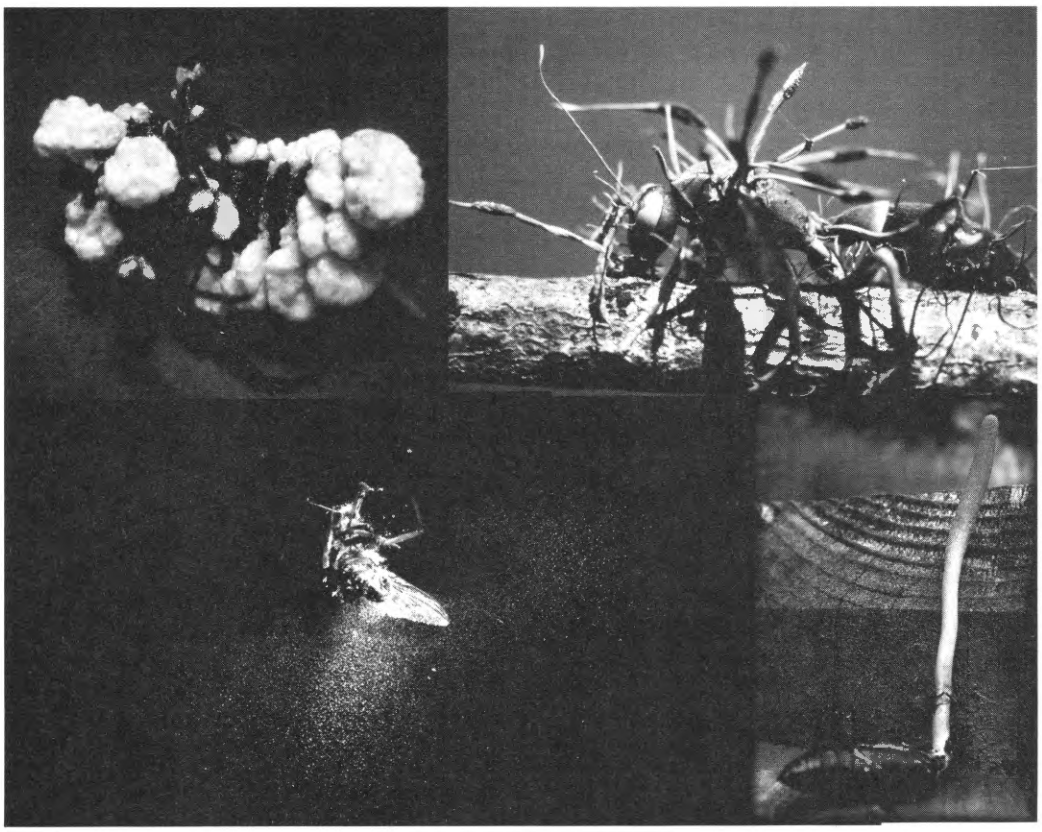
The spores or yeast cells of these fungi spread through the vasculature (xylem) of plants where they remain as asymptomatic endophytes until the plant becomes weakened. Common species are found in the Oomycota *Pythium* and Ascomycota *Fusarium* genera. Eighty different strains of *Fusarium oxysporum* are known, each of which specialize on a different crop. Most of these fungi survive by producing thick, asexual *chlamydospores* that can survive in soils for years. When the plant host is healthy, this fungus can confer many benefits such as increased yields in bananas.[103]

Ripe Fruit Lovers

These opportunistic fungi consume the sugars in fruits, often by entering wounds caused by insects or during harvest. They produce pectinases that break the pectin "glue" that holds plant cells together. Though farmers consider these fungi a nuisance, not all are considered bad. *Botrytis cinerea* produces bunch or "noble" rot on grapes. The resultant flavor in these grapes is used to create *botrytized* wine, a style highly regarded for its complex flavors. As such, some vineyards intentionally inoculate grapes with this fungal "problem."

Entomopathogenic Fungi

A variety of fungi in the Ascomycota and Zygomycota (order Entomophthorales) infect the bodies of living insects. In 1807, the first demonstration of the germ theory of disease was presented by correlating muscardine disease in silk worms to an infectious fungus, *Beauveria bassiana*. This fungus grows through the insect, where it releases toxins and absorbs water and nutrients from the host, effectively crystalizing the insect's hemolymph and hardening its body. For decades, this and other species of entomopathogenic fungi have been intentionally cultivated and applied as a "bioinsecticide" to control insect populations. Species in the *Coelomomyces* have been explored for their biocontrol of mosquitoes. *Leucanicillium lecanii* is one of the most effective, though *Beauveria bassiana* (e.g. strain GHA or strain ATCC 74040) is still used to kill white flies, ants, grasshoppers,



(Top left) A Beauveria *species strikes again. This genus is well-known for its potential as both a pesticide and endophytic inoculum.*

(Top right) An unidentified Cordyceps *species engulfs an ant.*

(Bottom left) The spore cloud of Entomophthora muscae *erupts from a house fly.*

(Bottom right) Cordyceps *species (here* C. militaris*) produce large, pimply fruit bodies from the heads of their host insect. Some of these fungi are revered for their medicinal potency.*

beetles, mites, thrips, aphids, weevils, and other insects. The conidiospores of the fungi are grown in a liquid media, harvested, and sprayed onto the insects.[104]

Many of these fungi alter the insect's behavior as an infection develops. *Ophiocordyceps camponotirufipedis* is well appreciated for its ability to create "zombie ants." Once an ant is infected, it will climb far beyond its normal range to the top of the tree canopy and bite down on a leaf. Soon after, the fungus mummifies the insect from the inside until, hours later, a mushroom erupts from the insect's head, releasing spores to rain down across the forest.

Many *Cordyceps* species are important for the maintenance of arthropod populations. *Beauveria* and *Metarhizium* are also common genera. Many entomopathogenic fungi are common plant endophytes in the Clavicipitaceae, a fact that strongly suggests that plant-insect interactions over the eons have helped spread, refine, and increase the impacts of these fungi throughout their ecosystem. *Massospora cicadina* attacks 17-year cicadas in a gruesome way that slowly corrodes the insect's body. *Entomophthora muscae* commonly infects flies. It is often witnessed on windowpanes where dead flies are found surrounded by a white halo of discharged conidiospores. The dead fly often has a distended abdomen with white conidiophore bands projecting between its exoskeleton segments.

Nematophagous Fungi

These specialized fungi infect, trap, and/or digest nematodes (microscopic roundworms that damage plant roots). More than 200 fungal species across phyla are nematophageous. They are found in all regions of the world, from the tropics, to Antarctica, to agricultural sites.[105] Their three primary means of killing nematodes are parasitizing nematode eggs or cysts, capturing the insect in adhesive or netted hyphae, or trapping the worms in constricting or non-constricting rings. The mycelial rings of *Hirsutella rhossiliensis* can trap a nematode in 0.1 seconds.

Animal Cullers

A wide variety of fungi negatively affect animals. Notable examples include the White Nose Syndrome in bats that is caused by *Pseudogymnoascus destructans*, various Oomycota that affect fish and their eggs, and the Chytrid *Batrachochytrium dendrobadis*, which has been attributed to the extinction of over 100 amphibian species over the last 40 years.

Numerous fungi affect humans with compromised immune systems or otherwise poor hygienic practices. For example, the fungi that cause athlete's foot and jock itch in humans (*Epidermophyton* and *Trichophyton* species) are rarely found free-living in public shower stalls and swimming pools, but instead are attributable to poor air flow and limited sun exposure in the infected areas. UV light will kill these fungi. About 20% of humans are also sensitive to high concentrations of *Alternaria* spores in the air and can develop seasonal "hay fever" in response to their spore release. *Malassezia* species cause dandruff by aggregating skin cells from the scalp into visible clumps.

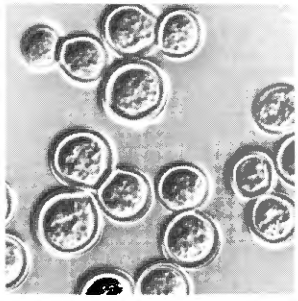
Candidiasis is a systemic infection of the body caused by *Candida albicans*. This yeast is normally present in the mouth and digestive tract, where it assists in various bodily functions, including digestion. However, when the body's microbial populations become unbalanced due to antibiotic consumption or dietary factors, this fungus can overwhelm the rest of the body's microbial flora, convert to a filamentous form, and cause damage to the host's body. Medicinal mushroom extracts can assist in overcoming *Candida* issues, though the root causes of the imbalance must be addressed to ensure symptoms do not recur.

Genital elephantitis can result from chromoblastomycosis, an infection attributed to various fungi in the Ascomycota.[106] *Cryptococcus neoformans* causes significant infections in the nervous system of immune compromised individuals, often forming abscesses in the brain that cause headaches, blindness, dementia, and death.[107] As it happens, this fungus also survives in the abandoned buildings of Chernobyl by converting gamma radiation into energy in a manner similar to the conversion of sunlight to vitamin D in human skin.

By far the most dangerous fungal pathogens for humans are *Histoplasma capsulatum, Blastomyces dermatitidis, Paracoccidioides brasiliensis,* and *Coccidioides immitis*—all Ascomycota in the order Onygenales. Though common saprotrophs in the soil, these fungi become serious human

pathogens when their spores are inhaled. This is due to their combined abilities to grow at 98°F (37°C), bind to human tissue, digest proteins, and evade the human immune system. Inside of lungs, these fungi penetrate into the alveoli where they cause severe tuberculosis- or influenza-like symptoms. This infection is probably coincidental, however, as it represents a dead end in the life cycle of these fungi and is thus not evolutionarily advantageous.

When *P. brasiliensis, H. capsulatum,* and *B. dermatitidis* cells are consumed by macrophages, these fungi defend themselves by raising the macrophage's internal pH, effectively disabling the digestive enzymes and "oxidative burst" typically employed by macrophages to destroy invaders. If the human's immune system becomes weakened, even years later, the dormant fungi inside of these macrophages can reanimate, causing a relapse in symptoms. Estrogen and other female steroid hormones inhibit these fungi, reducing their presentation in women by 10-fold when compared to men. Due to the severity of their effects, only highly regulated laboratories are permitted to study these lethal fungi.



The deadly spores of Blastomyces dermatitidis.

Recomposing Life: Saprotrophic Fungi

Across all marine and terrestrial habitats, fungi are found performing 90% of all decomposition on Earth. Among their ranks are the molds that break down left over food, the Chytrids that consume pollen, the recyclers of animal and plant debris, the destroyers of human-made materials and toxins, and the creators of nursery logs that feed future generations of trees. At the end of every life a doorway opens, exposing a mycelial bridge toward another birth. The fungi carry life across this dark abyss of death and expose each form of energy to another undulation in the endless waves of Nature.

Like all beings, fungi take in nutrients and transform these substances into new compounds that other species use to survive. To associate fungi with death and define them as *decomposers* simply because some of their primary foods are dead animal and plant parts is to ignore the fact that humans kill and digest the same organisms. Along with all of Earth's inhabitants, fungi should instead be seen as *recomposers* of the elements that bring evolution forward, albeit the most industrious in the process.

To give a sense of the importance and intricacies of decomposition cycles and some of the critical ways that fungi return nutrients back to the air and soil web, below is a summary of the ecology of decay wood (a.k.a *deadwoodology)* and the successional stages that a tree goes through as it returns to the Earth.

1: Epiphytes

Epiphytic fungi harmlessly live on the exterior of living plants where they may play beneficial roles, similar to endophytic fungi. However, the "head-start theory" proposed by some deadwoodologists also suggests that some epiphytes (and endophytes) may live asymptomatically until the plant becomes weakened or damaged, at which point the fungus will begin to actively feed on it. Likewise, endophytes are strongly associated with initiating the decomposition of fallen leaves.

Though epiphytes may live only millimeters away from the endophytes inside of the plant, the two fungal communities may be distinct. However this line may blur in several instances, as during the period in which horizontally transmitted endophytes exist epiphytically before entering plant tissues, and when internal plant tissues become exposed to the environment. This scenario effectively turns endophytes into epiphytes.

Nature assembles and breaks down, dissolves and renews, using the same material over and over, leaving no landfills and toxic dumps in her wake. In nature, there is no such thing as waste. Everything is food for something else, connected in life and death to many other species.

—Toby Hemenway[108]

2: Heart Rot

Heart rot fungi grow through the interior of living trees, but do not consume the outer cambium layers of the tree that keep the tree alive. As these fungi grow, they consume the tree's heartwood, which is not actively growing, but primarily acts as a storage site for the tree's waste products that cannot be expelled through its leaves or roots.

Heart rot infections occur when the bark of a tree is damaged, allowing nitrogen-fixing bacteria and fungal spores to enter the tree. As the two organisms grow, the bacteria provide the fungus with nitrogen and the fungus provides the bacteria with other forms of nourishment. Over time, the mycelium hollows out the center of the tree, forming a *decay column* inside the trunk. When these trees are cut down by the logging industry, this column forces the tree to be excluded from harvest, thereby lowering profits.

In short time, the decay column comes to host a diversity of animals and insects. Termites or carpenter ants begin to cohabitate with the mycelium in the tree's core, and as branches rot and fall off, birds and other animals begin to find shelter in the tree hollows. Woodpeckers may even use the fruit bodies of *Phellinus pini* to help indicate where decay is pronounced and thus find sites of suitable habitat.[109] Eventually the interior support of the tree becomes so reduced that the tree falls over, leaving its hollow snag and branches to serve as a critical habitat for a myriad of wild animals.

3: Pioneering "Goodie Gobblers"

Once a tree dies (whether due to heart rot, root rot, animal predation, or disease), various fast-growing and short-lived fungi (e.g. *Mucor* and *Rhizopus* species) and bacteria will appear to consume the easily obtainable surface sugars and proteins.

4: Secondary, "Easy" Polymer-Degrading Fungi

Overlapping with the pioneering organisms, secondary decomposers degrade moderately complex plant polymers (e.g. cellulose, hemicellulose, glucans, and pectins). To defend their substrates from competitors, these fungi will often sequester limiting nutrients (e.g. nitrogen) or produce inhibitory metabolites.

5: Recalcitrant Polymer Degraders

After the more accessible nutrients have been consumed, the more industrious fungi appear and degrade the persistent plant polymers of lignin, lignocellulose, and keratin. There are three main types of these important recomposers:

White Rot Fungi *(ca. 2,000 species)*

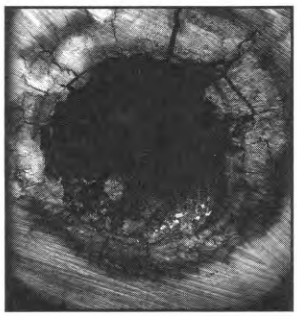
The majority of carbon in terrestrial ecosystems is locked up in lignocellulose, a matrix of woody material that comprises the bulk of trees and shrubs. However, the carbon in this material is inaccessible to most microbes due to the lignin component of wood. Lignin is one of the most recalcitrant compounds that Nature produces, only being degraded by a relatively small group of fungi. Lignin decay is critical in the global cycling of carbon out of wood and back to soils and plants. Further, as humic substances appear to be modified forms of lignin, it has long been argued that white rot fungi are intimately tied to the creation of the soil humus that holds water and nutrients for plants and microbes. Thankfully, however, fungi cannot fully digest lignin or use it as a sole carbon source. If this were the case, many of the byproducts of delignification that lead to the development of humus would not exist, prohibiting the development of soil and, by extension, the diversity of life we find today.

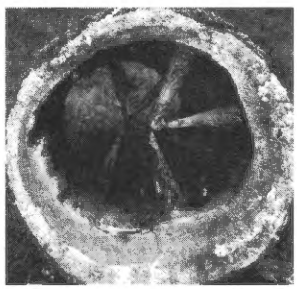
With the lignin degraded, much of the plant cellulose is left behind, giving the material a white appearance and little structural integrity. White rot fungi are found in both the Ascomycota (e.g. *Xylaria spp.*) and Basidiomycota (e.g. *Armillaria, Trametes,* and *Pleurotus spp.*) and tend to occur on hardwood trees (angiosperms) more commonly than on softwood trees (gymnosperms).

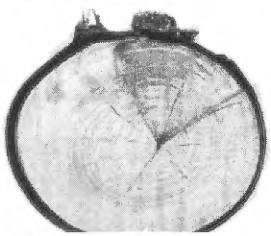
Brown Rot Fungi *(ca. 200 species)*

These fungi primarily degrade tree cellulose, potentially by means of a reaction between iron ions and H_2O_2, producing destructive hydroxyl radicals.[110] Brown rot fungi leave the bulk of the tree's lignin behind, which takes on a cubical or stringy appearance that breaks down to a fine powder. The resultant material is very resistant to further degradation and, in effect, acts as a type of natural sponge that holds water and nutrients, and provides refuge for insects and microbes. Tree roots, ECM fungi, and nitrogen-fixing bacteria are often found in abundance near brown rotted material. The preservation of brown rot fungi and the cubical rot they produce should therefore be heavily considered in any long-term forest conservation strategy.

Many conks are brown rotters. They are common on confinerous wood, with *Fomitopsis officinalis, Phaeolus schweinitzii,* and *Phellinus pini* being some of the primary degraders on these trees. Some species, such as *Ganoderma applanatum* and *Heterobasidion annosum*, can interestingly produce both brown and white rot in the same wood.







Soft Rot Fungi

Soft rot fungi are often found in damp areas and bioregions where they decay fence posts, window frames, and marine wood. They primarily eat cellulose and hemicellulose but can also degrade lignin slowly, leaving a distinct rhomboidal pattern in decayed wood. Most are soil-inhabiting Ascomycetes (e.g. *Chaetomium* and *Pleospora spp.*), though some are Basidiomycota as well (e.g. *Heterobasidion annosum*, a butt rotter). This group includes members of the genera *Allescheria, Graphium, Monodictys, Paecilomyces, Papulospora, Thielavia, Daldina, Hypoxylon*, and *Xylaria.*

(Top two) Decay columns caused by a heart rot fungus.

(Bottom) Schizophyllum commune *white rot forming a V-shaped decay section in a tree round.*

Polypore Genera Distinctions	Niche		Hyphae		
	White rot	Brown rot	Monomitic	Dimitic	Trimitic
Albatrellus			•		
Bjerkandera	•		•		
Bondarzewia	•			•	
Bridgeoporus		•		•	
Ceriporia		•	•		
Ceriporiopsis	•		•		
Cerrena	•				•
Chondrostereum	•			•	
Climacodon	•		•		
Cryptoporus		•			•
Daedalea		•			•
Daedaleopsis	•				•
Daldinia	Ascomycetes / Soft rot				
Echinodontium	•			•	
Fistulina		•	•		
Fomes	•				•
Fomitopsis		•			•
Ganoderma	•				•
Gloeophyllum		•			•
Grifola	•				•
Inonotus	•		•		
Ischnoderma	•			•	
Laetiporus		•		•	
Lenzites		•			•
Oligoporus		•	•		
Oxyporus	•			•	
Phaeolus		•	•		
Phellinus	•			•	
Pileodon			•		
Piptoporus		•		•	•
Polyporus	•			•	
Porodaedalia	•			•	
Pycnoporellus		•	•		
Pycnoporus	•				•
Rigidoporus	•		•	•	
Sparassis		•	•		
Trametes	•			•	
Trichaptum	•			•	
Tyromyces	•		•	•	

Mycophagy in the Animal Kingdom

As with humans, a wide number of animals and insects lavishly consume truffles, mushrooms, mycelium, and lichens for food and medicine. Fungi form an integral component to these diets, an ecological impact that travels up the food chain in countless directions. Though it is possible that mycophagy is commonplace throughout the animal kingdom, only a few key species have been thoroughly investigated for their fungal relations.

Ants and Leucocoprineaceous Fungi

As with ambrosia beetles (see p. 47), a variety of ant species also cultivate fungi for food. However, considering that leaf-cutter ant queens are some of the longest-lived queens of all social insects, it is possible that the mycelium may be medicinal for the ants and not solely nutritive. This ancient form of mycophagy arose approximately 30 million years ago and now takes on several forms.

- Around 8–10 million years ago, leaf-cutter ants in the genera *Atta* and *Acromyrmex* began cultivating *Leucoagaricus gongylophorus*, a fungal species that is now entirely dependent on the ants for survival. The ants feed the fungus pieces of leaves and other organic material in underground nests, and the resultant mycelial mass is eaten by the insects. The fungus is apparently not harmed in this process, just culled. When the ants abandon the nest, mushrooms arise for the first time from the mycelium that is left behind.[114]

- About 20 million years ago, a few ant species in the genus *Cyphomyrmex* began cultivating a distinct clade of unusual fungi in the Agaricales that grow as mycelia in the wild but as yeasts when tended by ants. These "gardens" are irregularly shaped, 0.5-millimeter-wide yeast clusters.
- Species of non-leaf-cutting ("higher attine") ants in the genera *Sericomyrmex* and *Trachymyrmex* cultivate fungi that are not found outside the ant nest.
- The ancient paleoattine ants (76 species) cultivate a wide range of fungal species that are found free-living in Nature.
- Tropical ants in the genus *Apterostigma* cultivate various coral fungi in the genera *Pterula* and *Deflexula*.

Termites and *Termitomycetes*

Like leaf-cutter ants, around 100 of the 1,800 termite species (all in the Macroterminitinae) cultivate and consume the mycelium of fungi in their nests. In Africa and Asia, these insects work with about 20 mushroom-forming species in the genus *Termitomycetes*. And, in a wonderful tripartite ecological web, when the termites abandon their mounds, large fruit bodies arise that the local humans gather and eat. *T. schimperi* forms the largest fruit bodies in the genus; it is found in Namibia, Tanzania, Ethiopia, Zambia, and Malawi.

Bees, Fungi, and Colony Collapse Disorder

In 2015, researchers discovered that a stingless Meliponini bee species from Brazil (*Scaptotrigona depilis)* intentionally cultivates a fungus as a necessary food source for its larvae. Specifically, it is a *Monascus* species with close genetic resemblance to *M. ruber* and *M. pilosus*. As each egg is laid in its brood cell, a liquid nutrient is regurgitated by a mature bee into the chamber. And as the larvae begin to hatch, the fungus grows out from the propolis that constructs the brood cell walls and consumes the liquid nutrients. The resultant mycelium is then eaten by the rapidly developing larvae, which would not survive without the fungus.

As the bee matures, it may continue to carry the fungus inside of its gut until it ultimately regurgitates it during the construction of other brood cells. It is currently unknown if the fungus confers protective benefits to the bee during this incubation period. Once a brood cell is used, it is disassembled and its propolis is reused to build other cells, effectively distributing the mycelium around the hive and even to new hives. Remarkably, this intentional spreading of the same fungal stock seems to be the only example of a swarming insect species actively propagating a fungus from colony to colony.

As discussed in Chapter 6, medicinal *Monascus* species have been used in Traditional Chinese Medicine for millennia. Though it is not known for certain that these bees obtain a medicinal or protective benefit from the fungus, it is quite plausible.[115] Indeed, the application of mushroom extracts derived from macro fungi, such as those discussed in Chapter 7, have been argued to improve the immune function of honeybees.[116]

Despite these promising revelations, the dynamics of bee-fungal interactions have only begun to be investigated, leaving many questions unanswered. It may very well be that in order for bees (and other insects) to best survive the onslaught of infectious agents in the environment, the combined support of fungal endosymbionts and externally sourced fungal compounds is required. Such internal and external fungal healing is found throughout the animal kingdom. However, as environmental destruction and the application of pesticides continue to threaten the survival of fungi throughout the world, any support they offer bees is constantly being decreased, making any study of these dynamics increasingly difficult.

Along with the variety of other environmental factors attributed to the decline in pollinator bee populations around the world (i.e. electromagnetic radiation, antibiotics, loss of habitat), a decline in symbiotic fungal populations is directly attributable to Colony Collapse Disorder (CCD). As such, one of the best strategies that apiaries, farmers, environmental activists, and citizen scientists

can take to end CCD would be to cultivate and apply beneficial micro and macro fungi in proximity to bee hives, if not integrate homemade medicinal fungal extracts directly into bee feeding regimens. To be effective, however, such campaigns would need to be paralleled with efforts to end the use of ecologically destructive pesticides, at a minimum. Though strategies for reducing CCD with fungi are still in their infancy, it is possible for any fungal cultivator to actively contribute to research in this important and pressing field using the cultivation and application of techniques outlined in *Radical Mycology*.

Waves of Marine Fungi

The oceans cover 70% of Earth's surface, and yet their fungal populations are scarcely understood. Marine fungi are associated with an increase in available nutrients following pollution and plankton blooms, relationships that imply these fungi are critical in nutrient cycling and increasing the resilience of oceans. It is highly likely that fungi are central in the decomposition of organic matter in marine systems, and providing essential vitamins, sterols, and amino acids such as lysine and methionine.[111] As elsewhere, this provision of nutrients by fungi ripples up the food web, enabling ocean life to flourish from the smallest fish to the largest whales of the sea.

To my knowledge, only 467 marine fungal species from 244 genera have been discovered thus far. In general, deep-sea sediment tends to have a low amount of fungal diversity, while Ascomycetes and Basidiomycetes tend to predominate in the oceans as a whole, with pink Basidiomycete yeasts being the most common isolate. Some of these fungi have DNA similar to known pathogens, suggesting fungal pathogens may be present in deep-sea environments. A study from 2009 also found many filamentous fungi living as endophytes in deep sea hydrothermal vents, where water pressures are extremely high.[112] Endolithic fungi seem to be common in the coral reef systems.

Mushrooms and Mammals

Along with being supported and nourished by internal fungi, many mammals also eat macro fungi in abundance as sources of food and medicine. Goeldi's monkey (*Callimico goeldii*) consumes *Auricularia auricula*, *Auricularia mesenterica*, *Ascopolyporus polychrous*, and *Ascopolyporus polyporoides* year-round. Dian Fossey documented that mountain gorillas will fight over Artist's Conk mushrooms. Female bettongs (rat-kangaroos) may even produce greater lactation as a result of increased mycophagy during the height of truffle season in Australia.[117] Various other Australian animals consume fungi, including the bush rat, potoroo, quokka, swamp wallaby, and brushtail possum. Around the world, bears, cows, deer, elk, pigs, rabbits, mice, snails, slugs, and many insects all eat mushrooms.

The most ecologically entwined examples of mycophagy are found in the actions of habits mammals, such as squirrels and voles. In the Northwestern US, the California red-backed vole is considered one of the few obligate mycophagists, with fungi constituting up to 85% of its year-round diet. The scat of these tiny animals has been shown to contain the spores of 19 different fungal genera, including several AM species. Truffles seem to be the primary food source for these rodents, with *Rhizopogon* spores being the most prevalent at 25% of those collected.[118] Apart from these true fungi, this animal's only other main food source is a fruticose lichen.

Many squirrels eat truffles and mushrooms, such as boletes and *Laccaria* species. Often, these animals will cache their fungal finds like cones and seeds,[119] or they may lay the mushrooms in the sun or hang them on trees to dry before caching.[120] This sun drying effectively increases the amount of vitamin D in the mushrooms, providing the animals with an important vitamin source for the winter months and year-round for nocturnal species. The animals are so adept at working with these fungi that they know to bite a piece off of the truffle skin prior to storage, so as to hasten drying in the truffle.[121] These stored truffles provide a rich source of other essential minerals, amino acids, and vitamins during the winter months.

After eating fungal fruit bodies, flying squirrels will launch through the tree canopy, dropping their pellets as they fly. These nutrient packets (Nature's "spore bombs") subsequently rain down balls of yeast, nitrogen-fixing bacteria, mycorrhizal spores, and nutrients. When they hit the forest floor, these pellets help fertilize and inoculate the trees in which the squirrel lives, helping ensure the survival of the tree through the subsequent mycorrhizal connections it will form and, by extension, increasing the resilience of the forest as a whole.

The Spiral of Succession

Ecosystems pulse along hyphal forces, moving into increasingly complex and dynamic arrangements. With unlimited potential held and exposed in each moment, no ecological web can be defined by discrete segments of time, just as no person can ever be in the same place twice. The rocks, water, and life forms that contribute to the world's biophysical cycles do not run in repetitious loops. They push their habitats along the trajectory of time, stacking waves of succession on top of—but never inside—those that came before. By instigating and propelling the nutrient cycles that fuel these exchanges, fungi define the curve of this endless spiral that remains forever balanced on the leading edge of its own expansion.

The organisms of the world are the notes of the music guiding this dance, with fungi acting as the conductors of each biome's grand orchestra. With perfect pitch, fungi tune the melodies of an environment. They strengthen symbiotic harmonies while eliminating the discordant imbalances that would otherwise drown out the timeless songs of Earth.

In the flow of carbon through a healthy forest, this centrality of fungi is incredibly clear. When plants photosynthesize, atmospheric carbon dioxide once expelled by animal breaths and fungal decomposition is converted into sucrose and, later, hexose. Travelling to the plant's roots, this sugar converts to fungal trehalose and mannitol as it passes through mycorrhizae and rushes across the mycelial network to the hyphal tip, building connections with other plants. This carbon goes on to feed endophytes, sustain orchids and other achlorophyllous plants, and produces truffles that are eaten by small animals.[123]

Example Mycophagists

Obligate
Western redbacked vole

Preferential
Camas pocket gopher
Creeping vole
Mazama redbacked vole
Southern redbacked vole
Heather vole
Northern flying squirrel
Western gray squirrel
Mantled ground squirrel
Yellowpine chipmunk
Long-eared chipmunk
Lodgepole chipmunk
Townsend chipmunk
Douglas squirrel
Red squirrel

Opportunists
California quail
Wild turkey
Stellar's jay
Grey jay
Mountain goat
North American elk
Mule deer
Fisher
Black bear
Grizzly bear
Virginia opossum
Pacific shrew
Trowbridge shrew
Wandering shrew
Yaquina shrew
Mountain cottontail
Rock rabbit
Bushy-tailed woodrat
Canyon mouse
Deer mouse
Pinon mouse
Mazama pocket gopher
Northern pocket gopher
Townsend pocket gopher
Sage vole
Long-tailed vole
Hoary marmot
Pacific jumping mouse

Accidental
Northern Spotted Owl

This top-down view of the Earth as a single system, one that I call Gaia, is essentially physiological. It is concerned with the working of the whole system, not with the separated parts of a planet divided arbitrarily into the biosphere, the atmosphere, the lithosphere, and the hydrosphere. These are not real divisions of the Earth, they are spheres of influence inhabited by academic scientists.

—James Lovelock[122]

The global lack of mycological awareness is typified by UNESCO's ranking of fungi only as mushrooms under "botany" and yeasts under "microbiology."

As these animals dig for fruit bodies, they break up the soil surface and create furrows that enable water to infiltrate and hydrate the ground, enabling more truffles to form. As the animal's spore-laden dung is deposited across the forest, it seeds new life when dung beetles carry it into the ground, further inoculating the rhizosphere. Down below, older hyphae die, leaving their carbon to feed and become the bodies of insects and small animals that make up the soil biota. While aboveground, small mycophagist animals become the food of owls and other predators, carrying the nutrients they hold one link higher on the food chain. In this common set of interactions, hyphae act as the tie that binds the wild together and transmits the flow of life-giving carbon from the sky across the terrestrial plane.

This flow is sensitive. For, just as the destruction of a habitat will irreparably disrupt soil webs, acts of deforestation threaten the loss of innumerable dynamics in an ancient ecosystem. In clear-cut areas, *Rhizopogon vinicolor* and other mycorrhizal fungi stop fruiting, leading to declines in vole populations and an inability in newly planted trees to thrive. Undoubtedly, similar impacts ripple out across the various understory plants and the fauna that intimately depend on fungi. Our overall understanding of fungal systematics is currently too limited for any accurate evaluation of how the loss of even one fungal species will influence an ecosystem in the short- or long-term. And as future disturbances to an ecosystem are unpredictable, ecosystem resilience must remain high to ensure its recovery from natural disasters. This is only possible through the conservation of biodiversity in threatened habitats.[124]

Sociologically, when an old growth, multi-canopied forest is clear-cut and replanted with straight rows of a single fast-growing timber species, the concept of a healthy forest ecosystem is lost to the humans that enter that space. Tree farms instigate a linear perception of what Nature is and what it is meant for. The monoculturing of these and other crops effectively attempts to control Nature by exhibiting one outcome of the reductionist framework in which the value of the natural world is described not in terms of beauty and integrity but of board length and bottom lines. Such attacks on the wholeness of Nature are ultimately attacks on the human self: a being born from Nature that inherently knows its deep-seated connection to its environment.

Rather than framing habitat protection policies around the population of threatened or endangered species, emphasis must be placed on the defense of the complex functional relationships that define whole ecosystems. Humans can only sustain endangered species for a short amount of time and only with substantial effort. It is when the species' natural habitat is provided for and protected that the plant, animal, or fungus will be able to adequately thrive on its own. To protect spotted owls is to protect the truffles that feed the mammals the owls eat, just as protecting rare orchids implies protection of the mycorrhizal fungi that they associate with.

When one learns to see the fungi being, they begin to experience and integrate an ecological perspective into all aspects of life. In the future expansion of mycological awareness, human survival will increasingly depend on a willingness to honor the importance of forming mycoinspired communities with allies across all branches in the Mycelium of Life. As the creators of the 21st century's legacy values and artifacts, learning to embody these lessons is part of the current human obligation to future generations. But, as this integration takes time in cultures that are consistently segregated from the natural world, such reflections can only begin with an eagerness to become like the fungi, to learn their histories, to work with them with respect, and to weave ourselves into the vast communities they endlessly design around us.

Chapter Three

Of the Hyphosphere

Since life first appeared on Earth, fungi have watched over the world's evolution. As novel life forms arose eons ago, the fungi found new habitats to dwell within and support. And as those beings died, the fungi around them helped recompose their bodies into the next generation. Weaving into fields and forests, the Fungal Queendom spread across time, holding onto ancestral forms that retain the same potency as they did long ago. Today, this reach has become so vast that fungi comprise the largest and most ancestral group of eukaryotic organisms in the Mycelium of Life.

If the entirety of Earth's history was compressed to a 24-hour day and today was midnight on that clock, fungi may have evolved as long as 18 hours and 40 minutes ago. In comparison, modern humans would have only existed for one second. As human cultures arose and developed in this short period, the wise and elder fungi led the way. Where beans and corn were planted to feed humans, fungi hid in the soil to assist in that nourishment. And as seeds travelled the world, fungal blights followed as hidden reminders of Nature's power over humanity's fate.[1]

To best anticipate where mycology is heading, these and many other historical intersections of human-fungal relations must be recognized for their richness of import. Fungi are among the most overlooked contributors to the history of humanity. By honoring mycophilic traditions and uncovering the deepest layers of these ancient intersections, Radical Mycologists of today can help build mycology's new era on the solid foundations laid by their ancestors. To begin, one must go farther back than may be imagined. For to support the growth of human cultures, fungi first had to create the world that humans eventually came to inhabit.

Pansporia, *Prototaxites*, and Paleomycology

Soon after Earth condensed from a cloud of space dust 4.5 billion years ago (bya), it was struck by Theia, a protoplanet approximately the size of Mars. Ripping 20% of Earth's mass into orbit, this powerful collision gave rise to two small moons that, eons later, fused to become the current Moon—a silver orb born in a dikaroytization of the night sky.[2] Down below, Earth's oceans slowly cooled as its solid material condensed into Pangaea, a great landmass of sterile rock.

Around 0.4-1 billion years later, cell-based life arose. It is generally assumed that the first cell was a simple prokaryote (bacterium),[3] though some researchers suggest that bacteria actually descended from the more complex cells of eukaryotes.[4] Regardless of its initial form, the exact time, place, and means by which life developed is unclear and heavily contested. The most commonly accepted evolutionary models claim that a perfect blend of chemicals floating in an ocean, pond, or the Pangaean atmosphere accidentally collided and formed proteins capable of reproducing RNA, DNA, and a cell membrane to contain it all.

However, considering the incredible complexity involved in the production of one functional

protein—let alone the thousands required to produce and maintain a healthy cell—this "primordial soup" theory has been dismissed outright by many scientists. Critics from Francis Crick, one of the discoverers of the structure of DNA, to the astronomer Sir Fred Hoyle have long argued that the spontaneous occurrence of life is so far beyond statistical probability that it should be considered highly implausible, if not impossible. Life on Earth, therefore, must have been introduced from outer space.

Counterarguments to this otherworldly theory of *panspermia* point out that such a notion simply moves the mystery of life's origin to another location. Still, it is not an impossible conjecture.[5] In recent years, astrobiologists have performed numerous experiments proving that microbes, fungal spores, molds, and lichens can survive the extreme conditions of outer space as well as crashing on a planet while inside of a comet.[6] Most notably, the lichens *Rhizocarpon geographicum* and *Xanthoria elegans* seem to be completely unaffected by the radiation, vacuum, and extreme temperatures of space. They can be placed into low Earth orbit for two-week periods and, upon retrieval, begin photosynthesis at pre-exposure rates. Lichens are also highly capable of surviving desiccation for indefinite periods of time, further adding to their potential interstellar resilience. So though a purely fungal origin of life (*pansporia*) has been suggested by mycophiles over the last few decades, it is perhaps more plausible that the mini-ecosystem of fungi, algae, and/or nitrogen-fixing cyanobacteria that we call lichens served as the inoculum of ancient Earth.

Whether of extraterrestrial or homegrown origins, ancient fungi do appear to have been present in the earliest epochs of our planet. However, putting a finger on exactly when they first developed is challenging. Compared to plants and animals, fungal tissue does not readily fossilize, leaving them poorly represented in the fossil record. There is strong evidence of fungal growth in 3.5 billion year old volcanic glass from the ocean floor,[7] and undescribed filamentous fungi have also been found in ancient oceanic basalt deposits.[8] The vast array of Chytrids, Ascomycota, and Basidiomycota found in deep-sea hydrothermal vents even suggests that the major fungal phyla diversified long ago in the oceans and not on land as is commonly assumed.[9] Indeed, the oceans may hold the keys to understanding the historical and ecological origins of fungi. But unfortunately mycologists and marine biologists have largely overlooked marine fungi, leaving our current knowledge of their origin extremely limited.

Whether born in the sea or on land, life for the first eukaryotic cells must have been incredibly challenging. On barren Pangaea, the only nutrient sources for these organisms would have been organic compounds, rock minerals, and the accumulating bodies of dead microbes. And in marine environments, the oxygen-poor and sulfide-rich oceans would have limited life to anaerobic creatures. The first eukaryotes would therefore have only been able to live if they could digest rock, eat dead organisms, and survive in anaerobic or otherwise harsh environments. When we look at modern fungi we find all of these traits, as well as many others that would have conferred great fitness under these extreme conditions. As many researchers have posited, it can therefore only be concluded that fungi were the first eukaryotic life forms on the planet.[10] In other words, the Fungal Queendom *is* the grandmother of all plants and animals on Earth today.

FUNGAL AND LICHEN SPECIES KNOWN TO SURVIVE THE CONDITIONS OF OUTER SPACE.

FUNGI
- Aspergillus oryzae
- A. versicolor
- Chaetomium globosum
- Penicillium roqueforti
- Sordaria fimicola
- Trichoderma koningii
- T. longibrachiatum

LICHENS
- Aspicilia fruticulosa
- Circinaria gyrosa
- Rhizocarpon geographicum
- Rosenvingiella
- Xanthoria elegans
- Xanthoria parietina

Currently, the oldest fungal fossils come from the Mesoproterozoic Roper Group in the Roper Superbasin of Australia. Dating to 1.5 bya, these sclerotoid specimens from the Ascomycete-like form-genus *Tappania* host branching, septate hyphae capable of anastomosis.[11] Considering the complexity of these structures, one must account for the time required for their evolution, suggesting that Ascomycete-like fungi were in existence as far back as 2 bya, if not earlier. *Tappania* fossils have also been found in shoreline carbon-rich shale deposits from Australia and China.

As fungi evolved over the early eons, so did plants. Generally, plants are thought to have first arisen approximately 1 bya when a eukaryotic cell engulfed a photosynthesizing cyanobacterium, forming a beneficial *endosymbiosis*.[12] But what was the early eukaryote that consumed the bacteria? Based on the material I have read on the topic, there is no clear explanation of what the first plant cell was or how it developed. But considering the evidence presented thus far, it is my belief that the first plant cell must have developed when an ancient fungus took a cyanobacterium inside of its tissue.

Though this may sound a bit myco-biased, such an act is performed by modern fungi. The glomeromycotan species *Geosiphon pyriforme* v. Wettstein incorporates and endosymbiotically

hosts the cyanobacteria *Nostoc punctiforme* inside of its swollen hyphal tips. Found in the upper layers of wet soils poor in inorganic nutrients,[13] this association has been suggested by some researchers to represent a step in the evolution of plants.[14] Research suggests that its underlying mechanisms of symbiosis may have even led to the development of the AM symbiosis.[15]

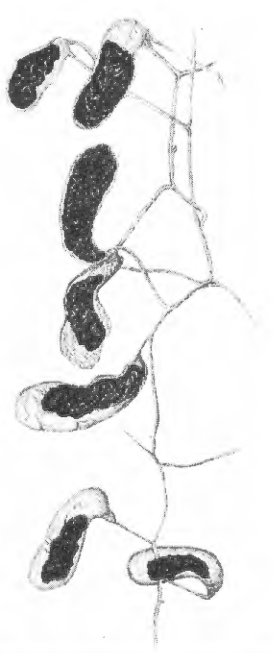
Looking at the cell wall of fungi and plants, one finds many strong similarities that also supports the notion of a common origin. Both of the primary structural constituents in these cell walls (chitin and cellulose, respectively) are comprised of modified glucose sugars joined by covalent β-1,4 linkages. In chitin, the monomer is *N*-Acetylglucosamine, while in cellulose the base unit is D-glucose (dextrose). The only difference between these compounds is that in chitin, one hydroxyl group is replaced with an acetyl amine group. Similarly, the sugars that make up 80–90% of the fungal cell wall are made of D-glucose bound with β-1,3 linkages. Today, at least 35 species of Ascomycetes are known to contain cellulose in their cell wall.[16] Therefore, it is highly plausible that in the billion years between the first fungal fossils and the assumed evolution of plants, an ancient fungus took in a photosynthesizing partner and, over the eons, modified its cell wall to the cellulose-rich form characteristic of plants today.

Around the same time that plants were developing, the animal kingdom also began to separate from its fungal ancestors. Based on the average rate of genetic mutations (the "genetic clock"), this is estimated to have occurred around 900 mya.[17] However, the oldest animal-like fossils are only around 635–542 million years old. These are the enigmatic Ediacaran creatures: tubular, fan-shaped organisms that have proved challenging to accurately categorize. They are commonly assumed to have been animals, however they may actually represent bygone fungal structures.[18] Similarly, the contemporary mushroom-shaped creatures *Dendrogramma enigmatica* and *D. discoides* share commonalities to three Ediacara genera, a likeness that suggests the *Dendrogramma* species have not changed their form in nearly 600 million years. Discovered off the coast of Australia in 1986, the *Dendrogramma* feed from the base of a stalk and channel nutrients up through a forked digestive canal that looks remarkably similar to gills under an agaric mushroom cap.

As plants and animals began to form these multicellular shapes, their first intimate relationships with fungi were set in place. One of the first of these came during the rise of lichens, when associations formed between ascomycetous and/or glomeromycotan-like fungi and cyanobacteria or algae (that is, assuming lichens did not come from outer space).[19] These early lichens likely formed in a variety of environments, climates, and water types, each with substrates of differing pH and stability. Such variety in habitats would have produced a range of proto-lichen forms and, in effect, multiple independent lineages of lichenization. Today, many lichenologists agree upon this general theory, through there is some disagreement on the number of lichen lineages. Estimates range from 5–12, depending on the data at hand. The oldest, cyanobacteria-based lichen fossils come from southern China and date to 551–635 mya.[20]

Largely constricted to the shores of Pangaea, these early lichens set the stage for later life forms to thrive. By demineralizing rocks and digesting the tissue of their deceased brethren, these proto-lichens and ancient fungi slowly penetrated the interior of the vast lithosphere and created the first soils of Earth.[21] Encountering new environments and substrates, they would have rapidly diversified as would have the *endolichenic* Ascomycetes living inside their structures (thalli). Thus, it was likely in the womb of early lichens that Ascomycetes, the largest fungal phyla and one of the most diverse and ubiquitous phyla of all eukaryotes, initially flourished.[22]

Over time, the algae in proto-lichens grew larger and more complex, eventually turning into the organisms we now call plants. As plants developed, some of their fungal partners separated and spread across the terrestrial plane,[23] while many others travelled inside of the plant tissues, becoming endophytes.[24] The simple, rootless plants known as hornworts may represent an intermediate stage in this transition as their simple, algal-like bodies host endophytes that curiously form arbuscule-like structures.[25] Endophytic fungi seem to have been found in hornwort fossils dating from the Phanerozoic era (ca. 540 mya).[26] As these and other early plants evolved (e.g. the ancient genera *Rhyniopsida and Horneophyton*), they took on simple bifurcating structures that resembled the growth patterns of the endophytes inside of them. Many of these early plants spread by means of spores.

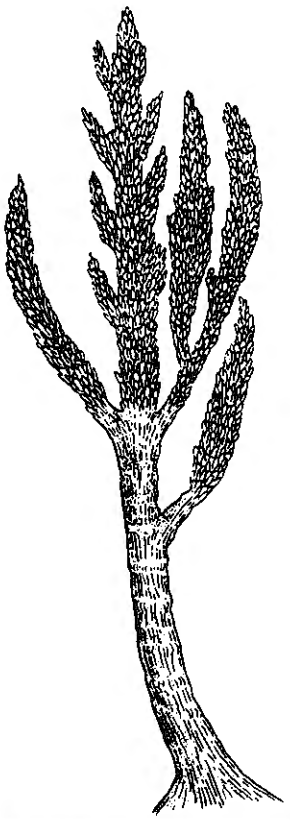


The Swollen hyphal tips of Geosiphon pyriforme *v. Wettstein endosymbiotically host photosynthesizing cyanobacteria. This fungus may be a relic of an ancient era when fungi helped transition microsopic organisms into the macroscopic structures we call plants today.*

These plants were among the first land plants with roots (bryophytes), which arose around the Mid Silurian era (ca. 700 mya).[27] As the plants began to grip and penetrate the accumulating soils, their endophytic associates descended to the novel root zone and began to form the arbuscular mycorrhizal association now common amongst the Glomeromycota. The oldest evidence of the AM relationship comes from *Aglaeophyton* fossils embedded in Ordovician dolomite rock uncovered in the state of Wisconsin, as well as from the Devonian Rhynie Chert of Aberdeenshire, Scotland. Dating to the Devonian era (ca. 460 mya), the roots of these ancient bryophytes contain vesicles and arbuscules that are morphologically identical to those of modern species in the Glomeromycota, along with spores similar to those from the genera *Scutellospora* and *Acaulospora.*[28] So it seems that at every leap in plant evolution—from their initial appearance in an early fungal cell, through their structural changes potentially influenced by endophytes, to the creation of soils and various mechanisms for accessing nutrients—fungi intimately carved the variety of forms that plants expressed throughout time.

This was an explosive era for evolution. As fungi and bacteria continued to build Earth's soils, a massive lichen-like organism began to appear on shorelines, towering over the insects and plants below. At up to 3 feet (1 m) wide and 26 feet (8 m) tall, these species from the genus *Prototaxites* were by far the largest organisms on the planet when they first appeared around 420 mya. And considering their significant abundance and diversity, they seem to have also been some of the most successful species in their habitat. *Prototaxites* existed for about 70 million years (i.e. until around 350 mya), more than three times as long as the genus *Homo* has existed.

With an anatomy unlike any living or fossil organism, *Prototaxites* specimens have been historically hard to classify, and various attempts to place them into evolutionary models have been repeatedly challenged. In cross-section, their fossils have concentrically arranged sections that are so similar to tree rings that specimens were originally thought to be small coniferous trees. However, in 2007, tests proved that due to the wide range of carbon types in their fossils, *Prototaxites* must have been a perennial fungus-based decomposer and a major recycler of organic life in their environments.[29] Further, as the majority of *Prototaxites* specimens are made of three types of interwoven hyphae (diameter <50 μm) that host clamp connections, their tissue may have been very similar to trimitic, woody polypores from the Basidiomycota. Cavities in them seem to have been bored by insects, suggesting the giant organism was a refuge for bugs, while their exterior was likely coated in algae, making it more like a giant lichen than a mushroom.



Early depictions of Prototaxites, *such as this drawing by John Dawson, presented the organism as a tree. This theory was so convincing that is was not disputed for nearly 30 years.*

Along with its classification, the shape of *Prototaxites* is also contested. For though this ancient sentinel is often depicted as a smooth column in contemporary artistic representations, it may have produced branches with large, scale-like "leaves," giving it an appearance similar to a conifer tree.[30] Confusingly, fossils of these leaf-like structures may be specimens from the extinct genus *Nematothallus*. The oldest trees come from the genus *Wattieza*, which co-existed with *Prototaxites* (ca. 385 mya). Like *Prototaxites, Wattieza* was a riparian organism that stood 26 feet (8 m) tall, however at its top this early tree hosted unique, spore-bearing, fern-like fronds, giving *Wattieza* an overall appearance similar to a giant Ascomycete mold conidiophore. These "branches" were regularly shed, sending the fronds to the forest floor in a manner similar to ways by which lichens replicate.[31] Other enigmatic, lichen-like "plant" fossils are found in the genera *Cosmochlaina* and the liverwort-like *Spongiophyton.* Eventually, around 360 mya, conifer trees increasingly replaced their *Prototaxites* look-alikes and began to host the insects that once inhabited *Prototaxites,* while taking on vasculature systems (xylem and phloem) with a rather hyphal-like form.[32]

All told, it must be asked if conifers (i.e. gymnosperms and/or their woody and spore-bearing kin from the progymnosperms) did not directly evolve from *Prototaxites* or a similarly massive fungus-dominant plant-fungus system. Just as lichens turned inside out and became plants, are conifers nothing more than a plant-dominant variation of *Prototaxites*? Did the woody, conk-like material of *Prototaxites* turn into the conifer wood that today is the common host for woody polypores, some of which contain the wood component lignin in their tissue?[33] Again, based on the evidence I have presented, I believe that it is highly possible that such evolutionary transitions did occur, yet I have found no contemporary reports or theories addressing the concept. Perhaps this oversight can be attributed to the general lack of fungi in standard evolutionary models. Or perhaps it calls too many

theories of evolution into question—a fungal challenge not readily resolved.

What is agreed upon (for the most part) is that the novel compound that gives wood its rigidity today (lignin) was indigestible by decomposing fungi when it developed during this era. Thus, as early trees and woody shrubs died, they began to accumulate. This pile up occurred for 60 million years, during what is now known as the Carboniferous Period (ca. 360–300 mya), until white rot fungi evolved with the ability to digest lignin. The plant material that was undigested eventually compressed, turning into the world's current coal deposits. In other words, the development of white rot was the temporal cap placed on the limits of coal reserves available today.[34]

As plants and animals continued to evolve, so too did their fungal ancestors. At some point, species in the Ascomycetes and Basidiomycetes began forming fleshy mushrooms, though we do not know if gilled or poroid fruit bodies developed first. Currently, the oldest mushroom fossil is an extinct *Marasmius*-like species (*Archaeomarasmius legletti*) that has been found in 90–94 million year old amber.[35] After the Permian-Triassic extinction event (251.4 mya), the fossil record shows an increase in fungal spore counts, suggesting that fungi proliferated on the abundance of dead plant and animal matter.[36] Around the time of the dinosaurs (the Mesozoic era, ca. 252 mya) plant-fungal symbioses took another leap, forming the ectomycorrhizal relationship.[37] However, the best evidence of ancient ECM fungi comes from *Rhizopogon*- and *Suillus*-like specimens dating to around 50 mya.[38] It wasn't until around 100 mya that ericoid mycorrhizae evolved.[39]

Similarly, as animals adapted to their changing habitats, they maintained an increasingly intimate link with fungi. Yeast-associated insects survived through extinction events, while later herbivores thrived by carrying fermenting fungi in their guts, just as cows host Chytrids today.[40] The proliferation of fungal spores from post-K-T extinction fossil beds (ca. 66 mya) point to another period of post apocalyptic fungal dominance.[41] This is yet another reminder that even in the darkest hour following the loss of most of the world's inhabitants, fungi will remain to recompose the fallen and carry life into future eras.

Many conks, such as the "living fossil" Echinodontium tinctorium are comprised of tissue that is remarkably wood-like.

Considering all of the above, it is rather incredible that most evolutionary theories have not accounted for the significant influences that fungi have held in the development of life. Admittedly, such a notion may sound unbelievable to those unfamiliar with the ubiquity and deep-seated relationships that fungi form with animals and plants today. However, to those versed in the resilience

Some of the oldest fossils of Prototaxites come from the Bordeaux Quarry near Cross Point, Quebec.

and importance of fungal biology and ecology, as well as the information above, such a theory must be considered for its potential validity.

Indeed, current genetic research is revealing that animals and humans may contain more fungal DNA than was previously recognized. In 2015, Crips, et al. stirred up the scientific community when they demonstrated that a range of beneficial gene sequences in humans and plants have been horizontally acquired (i.e. not derived from mutation but by copying) during later-stage interactions with fungi and other microbes. For example, the human genes that code for the production of hyaluronan synthases were inherited from fungi. This enzyme works with *N*-Acetylglucosamine (the building block of chitin) to create a type of lubricant for the intercellular space. It is exuded from human cells, just as hyphae release various compounds outside of their tissue. To quote the paper directly:

> *"[W]e identified up to hundreds of active foreign genes in animals, including humans, suggesting that HGT [horizontal gene transfer] provides important contributions to metazoan [animal] evolution... We argue that HGT has occurred, and continues to occur, on a previously unsuspected scale in metazoans and is likely to have contributed to biochemical diversification during animal evolution."* [42]

Another study has shown that over 17% of the DNA in the resilient microscopic creatures known as tardigrades, or "water bears," was horizontally transferred from other organisms, including fungi.[43] Indeed, these and similar studies increasingly suggest that the Tree of Life truly is much more like a mycelial web (the Mycelium of Life) in which distant lineages are linked by bridges of exchanged genes. Today, humans share 80–85% ribosomal DNA with fungi, making it hard to kill a severe fungal infection without killing its human host. Though much of this similarity was inherited through our common ancestry, some may be derived from more recent encounters with our fungal kin. And perhaps fungi are still interacting with our genome in unseen ways, subtly and slowly shifting the evolution of humans toward new horizons, just as they have always done.

Ethnomycology

In 2010, the remains of an 18,700-year-old woman were uncovered in a cave near Cantabria, Spain. Covered in a thick dust of red ochre and lavishly adorned in yellow flowers, the ritualistic burial was attributed by anthropologists to a female leader amongst the widespread and artistic people of the Paleolithic Magdalenian culture. Known as the Red Lady, the woman's corpse was a rare find for a region not known for Magdalenian tombs. For mycologists, it was also notable for the insights it shed into human-fungal relations of the deep past. For, much to the surprise of researchers, the Red Lady's teeth were covered in the ancient spores of several mushrooms from the Agaricales and Boletaceae,[44] unprecedented evidence that the Magdalenian people consumed fungi for food and potentially medicine. This single finding set the history of human-fungal relations—the study of which is known as *ethnomycology*—to more then 10,000 years earlier than was previously acknowledged.[45]

Adding to the reverence surrounding her burial, the Red Lady's limestone grave marker was adorned with a V-shaped carving, a symbol commonly thought to refer to the vulva or female pelvis in the ancient writing system of "Old European."[46] In this pre-Sumerian alphabet, the inverse of this symbol (the chevron) was used to signify the cap of a mushroom,[47] while the combination of the two—the zig-zag—denoted water.[48]

Several questions come to my mind regarding the final days of the Red Lady: Were these mushrooms a part of a ceremonial final meal? If so, were the agaric spores from *Amanita muscaria*, a red mushroom known for its vast historical significance? If she was a leader, were mushrooms only for the elite or did everyone in the culture consume them? Though these questions are currently unanswerable, it is quite possible that mushrooms may have played a central role in the Magdalenian culture or that they even revered them or reserved them for the highest members of the tribe. For, as any study of ethnomycology will attest, many of the world's most advanced ancient civilizations exalted fungi, especially mushrooms, often placing them amongst the most divine foods on Earth.

In the Papyrus of Ani (a.k.a. The Book of Going Forth by Day or The Egyptian Book of the Dead), mushrooms are called "the food of the gods," "celestial food," and "the flesh of the gods." Mushrooms were considered "plants of immortality" created by mushroom-seed coated lightning bolts hurled to Earth by Set, the Moon swallower and the red god of storms, chaos, darkness, destruction, and death. Yet despite these seemingly negative associations, mushroom consumption was an exclusive privilege of the pharaoh and his high-born companions. 4,600-year-old hieroglyphs forbid commoners from even touching mushrooms, while pillars in ancient Egyptian temples were shaped like huge *Amanitas* and *Psilocybes* with tall stems, umbrella caps, and mushroom-shaped engravings.[49]

The Greeks must have inherited the Egyptians' mycophilia for, as the historian Suetonius noted, they too considered mushrooms to be *broma theon*, a "food of the gods." According to legend, 3,500 years ago the Greek god Perseus—slayer of Medusa and son of Zeus—either picked mushrooms or dropped his cap (both items called "mykes") at a site in ancient Greece. Liking the place, he named it Mycenae and founded a town there.[50] The goddesses Persephone and Demeter are connected to mushrooms as well as the Eleusian Mysteries, a Greek ceremony that may have incorporated the use of psychoactive fungi, as discussed in Chapter 12.

Many other goddesses have been attributed to mushrooms throughout history. In Celtic mythology, the goddess Brigid was related to birch trees, mushrooms, medicine, and fire. These connections are notable as the growth of many important medicinal and flammable mushrooms is associated with the sacred birch tree, including Amadou, Chaga, the Birch Polypore, False Tinder Conk, and the fire-colored Fly Agaric. She was traditionally celebrated at the beginning of spring on Imbolc (February 2nd), the mid-point between the winter solstice and the vernal equinox. In the Scottish Highlands and potentially Sweden, the Beltane fires of May 1st were started with combustible fungi growing on birch trees (likely Amadou). In China, the goddess of healing and mercy, Kuan Yin, was closely associated with Ling Zhi (Reishi). It is also in China that we find the richest and oldest documentation of a culture incorporating fungi into rituals, artwork, and the preparation of food and medicine, as discussed in coming chapters.

In North America, historical and contemporary accounts of Native American and First Nations people working with edible or medicinal mushrooms are quite limited. The use of puffball spores for healing seems to have been one of the more common practices between nations. The Cherokee, Chippewa, Haida, Kiowa, Kwakiutl, Makah, Menomini, Pawnee, Omaha, and Navaho (Dineh) all mixed puffball spores with spider webs for use as a hemostatic.[51] The Navajo also mixed liquids with the spores of *Lycoperdon* and *Calvatia* puffballs to make a type of lotion. Other groups used puffballs and earthstars to stop bleeding and prevent infection when cutting an umbilical cord, while some tribes rubbed puffball spores on the navel of infants to prevent bedwetting. Empty puffballs were also filled with pebbles to make spiritual rattles or good luck charms. The Blackfoot Nation considered puffballs to be indicators of supernatural events. In northern Mexico, *Lycoperdon marginatum* is used by shamen to travel undetected, while the Mixtec in the southern end of the country use *L. mixtecorum* to induce a half-sleep state. Across the world, Australian Aborigines use the Desert Puffball (*Podaxis pistillaris*) as a dye for white hair and as a smoke for repelling flies.

Various Native American groups have historically worked with other fungi and lichens as a pigment source. The Navajo use *Endothia singularis*, a canker on Gambel oak *(Quercus gambelii)*, for this purpose.[52] The Kwakwaka'wakw have mixed *Echinodontium tinctorium* with deer fat or resin from western hemlock trees to create a face paint used in war. This toothed conk was traded amongst many tribes, some of which would use it for sunscreen, insect repellant, and tattoo ink. The Hopi used the black spores of Huitlacoche *(Ustilago maydis)* as body paint.[53] And in prehistoric times, people of the Tusayan Pueblo used the same pigment to create pictographs.[54] Despite being prized by the Aztecs and other cultures in Mexico as a valuable food source, there is surprisingly little evidence that Huitlacoche was eaten by Native Americans.

Quite surprisingly, there is little documented evidence that Indigenous people of North America consumed a variety of mushroom species. In the southwest U.S., the Zuni consumed puffballs fresh and also dried them for use during winter months.[55] And in the Taos Pueblo of New Mexico, *Tricholoma populinum* was traditionally eaten. Similar, scattered reports can be found throughout

Wrapping the Maypole by women is a fertility-revering, traditional aspect of the Beltane celebration.

The Maoris of New Zealand grind the dried bodies of caterpillars infected by Cordyceps robertsii *as a pigment for tattoos.*

the continent. However, in mushroom-rich areas such as the Cascadia bioregion of the northwestern U.S. / southwestern Canada or the northeastern U.S., most Indigenous cultures seem to have avoided the abundance of gourmet Chanterelles, Boletes, and Morels in their area.

Compared to the above areas of the world, the orally transmitted mycological knowledge of many African cultures has barely been documented in a few regions. Tanzania is known to host *Termitomyces, Agaricus, Boletus, Pleurotus, Cantharellus, Macrolepiota, Ganoderma,* and *Geastrum* species. In the Kilimanjaro part of the country, puffballs are traditionally used for wound healing. Mushrooms in *Termitomyces, Pleurotus, Lentinus, Lenzites, Trametes, Ganoderma, Pycnoporus, Coriolopsis*, and *Calvatia* are used medicinally in Nigeria. There, the Yoruba tribe uses ground *Calvatia cyathiformis* and *Daldinia concentrica* as a douche to treat leucorrhoea. In Burkina Faso, ashes of *Parkia biglobosa* are applied to the chest of children with respiratory distress. And in Mali, the Dogon associate mushrooms with stomach lining and drum skins, the latter of which they rub with mushroom ash to give the instrument "voice."[56]

Some of the most culturally important fungi in Africa, the Middle East, and Mediterranean regions are desert truffles from the genera *Terfezia, Delastreopsis, Balstonia, Delastria, Leucangium, Mattirolomyces, Phaeangium Picoa, Tirmania*, and *Tuber*. Known in North Africa as *nabat al radh, asqal, bidat el ardh,* and *banat ober,* and in the Arabian Peninsula as *al-kamaa* or *al-fag'a,* these edible and medicinal fruit bodies are revered by cultures in many countries, including Morocco, Algeria, Tunisia, Libya, Egypt, Israel, Jordan, Syria, Saudi Arabia, Iraq, Bahrain, Kuwait, South Africa, and Botswana. The Khoisan people (a.k.a. Bushmen or San) of South Africa eat truffles (which they call *kuuste* or *n'xaba*) from the genera *Kalaharituber, Eremiomyces,* and *Mattirolomyces*. The Khoisan also believe that truffles counteract the effects of poisoned arrows in shot animals. Hunters even keep a piece of *kuuste* with them as an antidote in case they are accidently wounded by a poisoned arrow.[57]

In the Old World, various cultures across Eurasia and Eastern Europe developed deep relationships with fungi. Slavic, Baltic, Catalonian, and Italian regions have particularly rich histories with mushrooms and truffles, each hosting cultural practices that are adamantly continued today. Up to 80% of Czechs and Slovaks spend at least one day per year gathering mushrooms. The contemporary Czechoslovakian pianist Václav Hálek transcribed and recorded many songs that mushrooms sang to him; his album, *The Musical Atlas of Mushrooms*, can be found online for free.[58] The Romanians hold such a strong relationship with fungi that they have over 1,100 common names for various mushrooms. Romanians even denote a person's "mushroom passion" with a specific term, *razh*. However, this *mycophilia* did not travel across the entire European continent, as evidenced by the relatively mycologically devoid history of the United Kingdom.

Terfezia *truffles such as these are a traditional delicacy in the Middle East and Africa.*

Fungi of Fire

Along with the commonality of puffball usage, woody conks are among the most trusted and cherished fungi amongst Indigenous cultures around the world. The strong hyphae of the Birch polypore, *Polyporus squamosus*, and *Fomes hemitephrus* have traditionally been used to sharpen the edges of weapons and tools. The Quileute used the position of shelf fungi to aid in orientation when returning from a walk. The Bella Coola of British Columbia perform a midwinter ritual known as kusiut, in which *Ganoderma* conks (called *känäni*) are made into puppets with arms and a scowling face. These puppets are then used by the *kusiut*, a person with healing powers.[59] As discussed in Chapter 7, many conks have also long been used as sources of internal medicine. However, it is in the burning of these woody fungi that one finds the most ancestral commonality amongst traditional cultures.

Tinder Conks

If thoroughly dried, Cramp Balls, Agarikon, Chaga, the False Tinder Conk (Punk Ash), and other woody fungi can be ignited and serve as a source of tinder. The Blackfoot traditionally travelled with burning pieces of the Red Belted Conk inside of a buffalo horn. Similarly, shelf fungi such as the Artist's Conk can act as an impromptu fireboard for bowdrills. If these conks are not available, the flammable white and brown rotted material they create can be used as an alternative fire starter. By piling dry brown rot material on top of white rotted wood (perhaps with a moss footing), one can spark the brown rot to create an ember until the white rot catches fire. Even on a rainy day, this material can be found dry and ready to use inside the heart of fallen logs.

The hoof-shaped polypore Amadou is the best-known fire starter fungus. The Athabascan people of Alaska and Northern Canada, the Cree of Northern Canada, and many European and Eurasian peoples traditionally used this fungus as a tinder source. And in recent centuries, its flammability was used to ignite the gunpowder in early flintlock rifles.

Amadou is so combustible that one can simply send a flint spark into the conk's pores and gently blow to create an ember inside the conk. However, the traditional practice for working with Amadou is to peel back its hard outer layer, exposing a soft, felt-like layer of mycelium below. This inner tissue can be removed and burned directly, or strips of it can be boiled in urine for several days and then dried for later use. Like adding saltpeter (potassium nitrate, the oxidizer of blackpowder), this process increases the flammability of the material.

Amadou (*Fomes fomentarius*)

Smudges and Smokes

Just as the plants Sage, Cedar, and Sweetgrass have long been burned by traditional cultures to cleanse the air, so too has the smoke of many fungi been valued as a healing smudge. Various Native American and First Nations groups traditionally burn puffballs (e.g. *Abstoma reticulatum, Bovista dakotensis, B. tomentosa,* and *Lycoperdon perlatum*) to ward off unwanted spirits. Similarly, the Ainu of northern Japan burned Amadou to banish bad spirits while the Khanty people of Siberia combined Amadou with silver fir (*Abies alba*) bark to create an incense for cleansing the house of a deceased person until their body was removed. The heat from this revered conk was likely also used by the Greeks to perform the healing act of moxibustion.

The Blackfoot, Cree, and Blood people of the North American plains traditionally burned the scented conk *Haploporus odorus* to produce a perfumed smudge. Elders in these groups also crafted leather necklaces and war robes decorated in oval-shaped, burnt-line-patterned pieces of the fungus.[60] The Cree burned Chaga as incense, while the De'ne' of Saskatchewan burned this fungus to divine the answer to questions. The inner material of Chaga would be rolled into two strips of equal length, with one strip corresponding to "Yes" and the other to "No." A question would be asked and the two strips burnt. Whichever finished burning first would provide the answer to the question.

The smoke of tobacco and Red Belted Conk was consumed by the Northern Dene of Canada to relieve headaches. Amadou has also been traditionally smoked with tobacco. For the Chuj of northern Guatemala, the combined smoke of tobacco and *Amanita muscaria* has long been used to bring about prophetic visionary experiences.

Long ago, Indigenous people of North America recognized that when combined with a highly alkaline substance, the effect of an alkaloid could be significantly heightened. In particular, the highly alkaline mineral content of *Phellinus igniarius* ash (a.k.a. Punk Ash) was reverentially combined with tobacco in many cultures to create what the Yup'ik of Alaska call *iqmik* ("things to put in the mouth"). Sucked or smoked, this blend potentiates the nicotine, creating a powerful effect in the user.

Canadian and U.S. museum collections show that iqmik was consumed by the Micmac of Nova Scotia, Inuit of Labrador, Blackfoot of the North American Plains, and Kwakiutl of the Pacific Northwest. Iqmik is so revered by these traditional peoples that the Punk Ash or its blend with tobacco was often protected in ornate wood, bone, or ivory boxes. Possessing iqmik was the sign of a successful hunter who was able to relax and share a smoke with others. In pre-contact times, the Denaina of the Alaskan interior also chewed a mixture of Punk Ash and balsam poplar bark.

Punk Ash *(Phellinus igniarius)*

Mycoligarchs No More

When mushrooms are around, there'll be war around.
—Russian proverb

The fungal cultivation skills used today have a rich history that spans the Earth. The origin of cultivating mushrooms seems to have been in China around 600 CE, when *Auricularia polytricha* was first cultivated by So. Two hundred years later, Han first cultivated Enoki. Some accounts attribute the development of Shiitake to the Japanese around 200 CE. However, it seems that the Chinese were actually the first to pioneer this practice around 1000 CE. According to writings by Zhang Shou-Cheng, Wu San Kwung developed Shiitake cultivation during the Chinese Sung Dynasty (960-1127 CE) in the Lung-Shyr Village of the mountainous Lung-Chyuan County in Zhejiang Province.

As the legend goes, Wu San Kwung frequently hunted wild mushrooms in the forested high mountains surrounding his village. One day, Kwung discovered that broken tree limbs produced what he called *shiangshyuhn* ("nice-smelling mushroom") and that if he cut the logs, the mushrooms would grow larger and in greater number. But if the mushrooms would fail to appear, he would become angry and beat the logs vigorously, stimulating the growth of more mushrooms. Eventually, the cultivation process was further refined until, in 1313 CE, Wang Cheng wrote down a Shiitake cultivation protocol in the *Book of Agriculture*. Cheng described cutting holes in maple (*Acer*), sweetgum (*Liquidambar*), or chestnut (*Castanopsis*) logs and then burying them in soil for one year. Afterward, the logs were to be covered with branches, leaves, and soil, and frequently watered with kitchen wastewater. A few hours after watering, a wooden club was then used to beat the logs and encourage fruit bodies to appear, a process known as *jingshiang* ("shocking the mushroom"). The practices of cutting, inoculating, soaking, and shocking logs still lie at the core of Shiitake cultivation today.

The importance of Wu San Kwung's contributions to Chinese agriculture was never forgotten. During the Ch'ing Dynasty, two major temples were built to honor the man, one in 1739 and another in 1875. There are also small temples dedicated to Wu San Kwung in almost every mushroom growing village. And every year from July 16 to 19 on the Chinese calendar, there is an all-day celebration to give thanks to the legendary mycological figure.[61]

Wolfiporia extensa *was first cultivated in 1232 by Zhou, and a* Ganoderma *species was first intentionally grown by Wang in 1621.*

Compared to this rich history, Western cultures took a rather long time to recognize the value of mushroom cultivation. The first European country to practice mushroom growing was France, beginning around the late 1600s. By 1707, mushrooms were being intentionally grown in French gardens. In 1729, the Italian botanist Pier Antonio Micheli was the first person to describe fungal spores, marking the birth of modern mycology.[62] Nearly seventy years later, *Agaricus* mushrooms began being cultivated in the limestone caves outside of Paris where temperatures and humidity levels were easy to control. These early practices were simple, with non-pasteurized horse bedding and other composted materials serving as the substrate and mycelium from previous crops used as the inoculum. With such non-standardized practices, results were often unpredictable and the art of mushroom cultivation in the West developed slowly.

Around the turn of the 20th century, protocols rapidly improved. In 1891, New Yorker William Falconer published the first book on mushroom growing.[63] And in 1900, Richard Falck determined how to cultivate *Pleurotus ostreatus*, initiating the transition from compost-based substrates to simple agricultural wastes. In 1903, Louis F. Lambert developed the first pure culture brick spawn for *Agaricus* production. By 1917, cultivators in Pennsylvania had begun developing strains from spores.[64] In the US, the *Agaricus* industry flourished in Long Island, Central Massachusetts, Chicago, Michigan, California, and especially southeastern Pennsylvania. This same year, the mycologist James W. Sinden at Pennsylvania State University discovered that sterilized wheat grain made a more robust spawn substrate than the composts that were being used up to that point. Today, grain spawn is a pivotal element in nearly all mushroom cultivation processes.

By the 20th century, the evolution of mycology was rapidly increasing. In parallel with the industrial revolution, this early era of the mycological revolution set the stage for the unprecedented human-fungal relations being defined today. In 1919, the pharmaceutical company Pfeizer™ developed practices for mass-producing citric acid by growing *Aspergillus niger* in large vats of sugar water, a practice known as *submerged fermentation*. After the discovery of penicillin by Alexander Fleming in 1928, this same liquid-based practice was used to mass-produce a wide variety of fun-

As early as 1905, various species from the genera Pleurotus, Coprinus, Agaricus, Armillaria, Calvatia, Lycoperdon, *and* Tricholoma *were actively being cultivated in the U.S.*

The Submerged Fermentation of Industrialized Fungi

The liquid cultivation practices pioneered in the early part of the 20th century are still practiced today to create a range of compounds that directly influence modern life. Of these, 39% are used in detergents, 14% are for textile processing, 12% are amylases used in starch processing, and the remaining 35% are used in food, health, and various other industries.

In the textile industry, fungal cellulases are used to remove loose clothing fibers and create "stone-washed" denim. *Trichoderma reesei* produces up to 40 grams of cellulases per liter of culture medium.[66] Fungal proteinases are used for a wide variety of textiles, including in the removal of fur during leather production. And when clothing becomes soiled, fungal proteinases, lipases, amylases, and cellulases are used to brighten clothes by removing broken fibers that scatter light and dull the cloth's color. Many stain removers use the lipase produced by *Aspergillus niger* to cleave water-insoluble fats and oils into water-soluble glycerol and fatty acids.

In the medical industry, fungal products include the antibiotics penicillin (the common penicillin precursor 6-aminopenicillanic acid [6-APA] is produced by *Penicillium chrysogenum*) and cephalosporin (produced by *Cephalosporium acremonium*). The immune suppressant cyclosporine, created by *Tolypocladium inflatum*, is used to avoid organ rejection in transplant patients. The fungus *Aspergillus terreus* releases mevinolin, a chemical that forms the basis for cholesterol-reducing statin drugs such as Pravastatin, Simvastatin, and Lovastatin. These three drugs are among the top ten selling pharmaceuticals worldwide, with combined sales valued at US$5 billion in the late 1990s. *Aspergillus terreus*, *Penicillium citrinum*, and Pearl Oyster also create statins. *Mortierella* species produce the polyunsaturated fatty acid arachidonic acid (ARA), which is used for lowering blood cholesterol, thereby minimizing the effects of cardiovascular diseases. ARA is also found in breast milk and is added to infant formula due to its importance in brain and retina development.[67]

Various compounds derived from Ergot (*Claviceps purpurea*) are used in low doses to cause vasodilation, lower blood pressure, and decrease smooth muscle contraction. More specifically, ergometrine is used to assist in third stage labor and reduce post partum bleeding These compounds are largely obtained from highly productive fungal strains that were developed by forced mutation. Despite the fact that these alkaloids can be synthesized, extraction from fungal cultivation still proves to be the most cost-effective means of producing these chemicals. *Saccharomyces cerevisiae* has been genetically modified to produce tetrahydrocannabinol (THC), the psychoactive compound in *Cannabis sativa*,[68] and opioids.[69] In the coming years, the production of these and other bioactive compounds are likely to become increasing derived from this workhorse micro fungus.[70]

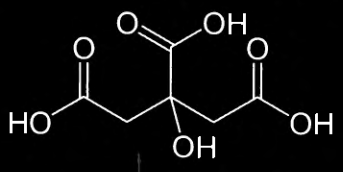
The chemical transformations performed by fungi and/or their enzymes can be applied to produce compounds that would otherwise be difficult, impossible, or prohibitively expensive to synthesize. Fungi can also be cultivated to synthesize complex nanoparticles faster than some chemical synthesis methods, a field of research known as myconanotechnology. In essence, aqueous metallic salt solutions are introduced to the fungus (e.g. *Aspergillus fumigatus* or *Fusarium semitectum*), which then synthesizes the nanoparticles internally and/or externally by using its own proteins. Fungi and/or their enzymes are also used to modify pharmaceutical steroids during manufacturing.

Apart from the more commonly recognized forms of fungal food production such as beer, bread, fermented foods, and mushroom cultivation, fungal products influence the food industry in a variety of ways:

- **Ethanol:** The ethyl alcohol produced by *Saccharomyces cerevisiae* fermentation has arguably been the single most important fungal metabolite used by humans throughout history. Found in alcoholic beverages, this combustible fungal product is, by volume, most commonly used as a rather unsustainable alternative to petroleum based fuels. Fermentation of cane sugar in Brazil is the biggest source of ethanol fuels.
- **Citric Acid (CA):** Along with ethanol, the citric acid created by *Aspergillus niger* is by far one of the most abundantly manufactured fungal metabolites in the world. In 2007, global CA production was nearly 1,600,000 tons, with over half being produced in China. CA is used in the production of beverages, foods, cosmetics, pharmaceutics, and various chemicals.
- **Amylases:** Amylases hydrolyze starches, converting them to sugar. Fungal amylases are used to sweeten foods and create high-fructose corn syrup.
- **Cheese production:** In place of animal-derived rennin (chymosin), vegetarian cheese is commonly produced using rennin derived from yeasts (e.g. *Kluyveromyces lactis*) and/or *Aspergillus niger* that have been genetically modified to express the gene for bovine rennin.
- **Brewing:** In beer production, fungal α-amylase, proteinases, and glucanases are often used to improve barley extraction during the mashing process that precedes fermentation.
- **Fruit juice and wine conditioning:** Fungal pectinases from *A. niger* are commonly used to help pulp and peel fruits and vegetables and to clarify wine or other alcoholic drinks.
- **Baking:** Xylanases produced by fungi can increase dough volume by increasing the amount of available sugar for yeast.

Many of the above compounds are produced using liquid cultivation processes similar to those described in Chapter 8. In essence, the fungus is grown in a simple broth containing sugars, minerals, and a nitrogen source. As the fungus grows through the medium, it releases the above chemicals into the liquid. Afterword, the fungus is filtered out and the chemicals are extracted from the liquid using relatively simple chemistry techniques. The broth may also be concentrated, as described in Chapter 7, or the enzymes may be precipitated, as detailed in Chapter 10.

For citric acid production, *Aspergillus niger* is grown in a 15% sugar solution (made from refined or crude sucrose, cane syrup, or beet molasses) that has been pH adjusted to 5-7. Over the course of 8-12 days, the mycelium is grown at 82-86°F (28-30°C), during which time the release of CA by the fungus lowers the pH to below 2.0. The mycelium is then filtered out and the acid precipitated from the liquid with lime (calcium oxide, CaO). The precipitate (tricalcium citrate) is filtered out and washed with water several times before being added to sulfuric acid, forming insoluble calcium sulfate in a liquid that contains CA. This CA is finally filtered, concentrated, and crystallized to produce citric acid monohydrate. This process is very similar to that used in 1890 to produce CA from citrus fruit.



Citric Acid

Type	Compound	Species	Application
Organic Acid	Citric acid	*Aspergillus niger*	Food, health, and various industries
	Itaconic acid	*Candida spp.*	Chemical industry
	Malic acid		Beverage and food industries
	Fumaric acid		Food industry
Vitamin	Riboflavin		Health industry
	Pyridoxine	*Pichia spp.*	
	Ascorbic acid	*Candida spp.*	
Antibiotic	Penicillin	*Penicillium chrysogenum*	Human and animal health industry
	Cephalosporin	*Cephalosporium acremonium*	
Fatty acid	Stearic	*Cryptococcus spp.*	Food industry
	Dicarboxylic	*Candida spp.*	Chemical industry
Alcohol	Industrial alcohol	*Saccharomyces spp.*	Fuel industry
	Drinking alcohol	*Saccharomyces spp.*	Beverage and food industries
Pharmaceutical	Lovastatin	*Monascus ruber*	Health industry
	Cyclosporin	*Tolypocladium inflatum*	
Amino acid	Lysine	*Saccharomyces* species	
	Tryptophan	*Hansenula*	
	Phenylanine	*Rhodoturula*	
Recombinant protein	Insulin	*Saccharomyces cerevisiae*	Treatment of diabetes
	Phytase	*Aspergillus niger*	Phosphate liberation
	Hepatitis B	*Saccharomyces cerevisiae*	Vaccine preparation

Type	Compound	Species	Application
Enzyme	α-Amylase	*Aspergillus niger*	Starch processing and food industry
		Aspergillus oryzae	
	Chymosin	*Aspergillus niger*	Food industry
	Cellulase	*Trichoderma viride*	Textile, pulp, paper industry, dehydrated foods, brewing
		Trichoderma reesei	
	Cellobiohydrolase	*Trichoderma viride*	Textile, pulp, and paper industry
		Trichoderma reesei	
	Glucoamylase	*Aspergillus phoenicis*	Starch processing industry
		Rhizopus delemar	
	Glucose oxidase	*Aspergillus niger*	Textile industry, biosensor
		Aspergillus oryzae	
	Laccase	*Trametes versicolor*	Textile, pulp, and paper industries
	Lipase	*Aspergillus niger*	Food and detergent industry
		Aspergillus oryzae	
	Pectin lyase	*Trichoderma reesei*	Food industry
	Proteases	*Aspergillus niger*	Food, detergent, and leather industries. Meat tenderizer, and for cheese manufacturing
		Aspergillus oryzae	
		Rhizopus delemar	
		Rhizopus oligiosporus	
	Phytase	*Aspergillus niger*	Food industry
		Aspergillus oryzae	
	Rennin	*Mucor miehei*	Food industry, and cheese manufacturing
	Xylanases	*Trichoderma reesei*	Textile, pulp, paper, and bakery industries
		Trichoderma konignii	
		Aspergillus niger	
	Amyloglucosidase	*Aspergillus niger*	Starch syrups, dextrose, foods
	Invertase	*Saccharomyces cerevisiae*	Confectionary industry
	Alcohol dehydrogenase	*Saccharomyces cerevisiae*	Ethanol assay
	Lactase	*Kluyveromyces lactis*	Dairy industry
	B-Glucanase	*Aspergillus niger*	Brewing
	Pecintase	*Aspergillus spp.*	Fruit juice clarification

At least 60 countries cultivate mushrooms. China, the United States, Netherlands, France, and Poland are the top five producers. Mexico, Chile, and Brazil constitute over 85% of the mushroom growing industry in Latin America.[74]

gal medicines and economically important enzymes. At the same time, mycological heavy hitters like Alexander H. Smith and Arthur Buller were actively revising fungal biological models and taxonomic schemes, helping set the high standards for naming fungi followed by professional and amateur mycologists today. This was also the era of untold numbers of mycologists and mushroom cultivators endeavoring around the world to decipher the complexities of fungal biology and ecology. Many of these superheroes are remembered online in the great halls of CyberTruffle's Fungal Valhalla.[65]

By the second half of the 20th century, fungal cultivation had become such an elaborate practice that small-scale growers found it challenging to compete with industrialized operations. With their big budgets, large mushroom farms were able to adopt the expensive equipment and intense cleanliness practices that were increasingly touted in the industry. And with emphasis still largely placed on *Agaricus* species, the mushroom market was relatively small and fiercely competitive.

At the time, there were few places to study mushroom cultivation (or mycology in general), leaving those interested in learning to cultivate at a loss for where to take up the trade. Beginners were often met with vague or misleading information from professional growers. And as the decades progressed, the few cultivation manuals that were readily available tended to be intimidating due to their insistence on impeccable standards, complex commercial procedures, and expensive equipment. The net effect was a limited spread of mycological knowledge beyond a small percentage of society, and a widespread false perception that mushroom cultivation *must* be difficult and expensive. Unfortunately, such barriers to accessing mycology have remained seeped into Western culture to this day.

It wasn't until the cultural reintroduction of psychoactive fungi in the mid 1950s that mushroom cultivation began to return to its homegrown roots. By the 1960s and 70s, counter culture desire to cheaply cultivate illegal psychoactive species led several writers to produce small books translating industrial practices to kitchen-scale techniques. Eventually these innovations were applied to non-psychoactive mushrooms with great success. In effect, this covert community of illegal mushroom growers directly helped release the skills of cultivation from the grips of the mycoligarchs, opening the Western world to low cost, yet highly effective mushroom cultivation practices.

This precedent continued to expand in the underground throughout the 20th century. However it wasn't until the advent of the internet that access to mycology and fungal cultivation became readily available to anyone with a computer and modem. The web forums Mycotopia and Shroomery[71] have been especially pivotal in this democratization of mycology, thanks to their cataloging of an incredible number of innovative techniques, tools, terms, and tricks developed by anonymous growers. Of particular note, this community's elegant breakthroughs in liquid-based cultivation practices over the last decade have created what I consider to be a complete sea change in how mushroom cultivation can and should be done. As discussed in Chapter 8, these practices are so cheap, simple, and effective that I do not doubt liquid-based cultivation will be instrumental to making the many gifts of fungi accessible to people around the world in the near future.

It can only be speculated where fungi will lead us. Undoubtedly, the future will be so myco-centric that many facets of human activity will look unlike anything practiced today. Access to fungal medicines will be widespread, while homemade, custom mycomedicines will become increasingly common. Many of the "wastes" currently produced by human activities will be fungal based (e.g. as mycelium-based products, described in Chapter 9) and/or used to cultivate mushrooms and regenerate the environment. Pyrolyzed fungal tissue may even replace the graphite in lithium ion batteries in the near future, creating a natural energy source with a significantly decreased toxic footprint.[72] As our understanding of fungal communication systems is further refined, human telecommunications and robotics systems may be developed that incorporate the intelligence of fungal epigenetic response and/or slime mold growth patterns.[73] Perhaps in the future, ecologists and naturalists will use technology to connect with Common Mycelial Networks spanning whole ecosystems and, through them, learn how disturbances are being addressed in the environment as well as where further recovery efforts are in need of greater protection. However, these and other potential means for working with fungi will only become common in the West when the many unexamined assumptions about these incredible beings are thoroughly exposed and overcome.

To Fear Fungi

The dream-wish rises like a mushroom out of its mycelium.
—Sigmund Freud

Of all the impressions fungi have left on human cultures, one of the most inexplicable is the widespread fear, or *mycophobia*, placed onto the Queendom. Why have so many cultures ignored the healing qualities of mushrooms? It can't simply have been, as some historians argue, because some mushrooms are poisonous. Most traditional cultures were and are masters of their environment, able to delineate between thousands of plant species. Deadly plants outnumber fatal mushrooms, and can even look like edible plants.[75] Likewise, it could not have been due to the inconsistency of mushroom hunting. Many plant crops are ephemeral, inconsistent, or otherwise hard to access. Hunting animals is a laborious task, often taking days or weeks to complete. Conversely, patches of easily identifiable mushroom species (e.g. Lion's Mane, Chanterelles, Chicken of the Woods) can produce annual crops, making them a reliable source of high quality food for even casual foragers. And if a given culture observed the mycophagy amongst other animals, it would have been clear that fungi are a valuable food.

Is it, then, that mycophobia is some sort of ancestral fear, woven into the human genome like the trepidation that follows snakes and spiders? Considering how many cultures have indeed thoroughly adopted fungi, the answer to this question seems to be "No." But where does this fear originate? Mycophobia must be a custom with a defined origin and rationale, otherwise, how could it persevere for so long?

Surprisingly, mycologists and historians rarely acknowledge the fact that, for no substantial reason, some cultures have chosen to fear a common element in their environment. Mycophobia is simply accepted as inconsequential, an acceptable trend—at least, as it is perceived by historians coming from their own fungi-fearing culture. On the other hand, I find the degree to which certain societies fear fungi not only intriguing but, upon deeper analysis, reflective of that culture's relationship with the world—a more cryptic and darker expression of human-fungal relations.

Observing decomposing mushrooms, one could propose, as many have, that mycophobia is merely an outgrowth of a culture's avoidance of death. Indeed, fungi have long been connected with the underworld, often being placed amongst other organisms in an etheric, indefinable state. Mushrooms have been called a "superfluous air" exuded by rotting substances and, as the 13th century philosopher Albertus Magnus described them, the result of rotting, not the cause of it. The Roman philosopher Pliny the Elder (23–79 CE) stated mushrooms were made noxious by the breath of subterranean serpents exiting their dens. In ancient Arabian texts, fungi were seen to be half-alive, somewhere between mineral and plant, just as 16th century herbalists claimed mushrooms existed between animate and inanimate states. Even the origin of the word "fungus" denotes this morbid association, coming as it does from the Latin *funus* (corpse) and *ago* (I make).

He wha tills the fairies' green
Nae luck again shall hae:
And he wha spills the fairies' ring
Betide him want and wae.
For weirdless days and weary nights
Are his till his deein' day.
But he wha gaes by the fairy ring,
Nae dule nor pine shall see,
And he wha cleans the fairy ring
An easy death shall dee.
—Traditional Scottish rhyme

Arising from the chthonic realm, fungi were often seen as bridges between the lands of light and dark. And wherever they would appear overnight in circles of bright, white mushrooms, humans would claim spirits had been at play. To many cultures, in entering these fairy rings one risked being carried to the land of pixies, potentially to never return. In the Netherlands, fairy rings are the resting place of the Devil's churns and in Ireland they are made wherever the Devil spills milk while making butter. In Germany, *hexenringe* ("witches' rings") are produced on the eve of Beltane by witches under high revelry. And in the Philippines, they are connected with diminutive spirits, just as Celtic and Scandinavian cultures claim they are the dance floor of spririts, fairies, and elves. The Blackfoot say the rings are created by the dancing steps of buffalo, while to the French *ronds de sorcieres* ("sorcerers' rings") have long been considered sacred. Some legends assert that the only way to safely investigate a fairy ring is to run around it nine times, so as to hear the fairies dancing underground. A 20th century English tradition states this must be done clockwise under a full Moon; to go the opposite direction would enable the fairies to catch the runner.

Fairy rings of Lepista sordida *can grow 2 mm a day, or 0.75 m per year. At more than 0.5 miles (600 m) in diameter and nearly 800 years old, a fairy ring of* Infundibulicybe geotropa *(*Clitocybe geotropa*) in France is thought to be the oldest ring in the world. Other fairy rings in the Midwest U.S. may be over 600 years old.*

If a culture also connected fungi to crop blights, associations with loss, illness, and death were undoubtedly reinforced. The Romans feared wheat rust so strongly that dogs were sacrificed to Robigus, the god of agricultural disease, during the festival of Robigalia in hopes of reducing fungus-producing rains.

However, this connection may also be historically uncommon—a more recent creation of monoculture farming practices framed through pre-existing biases. Take for example, the so-called Irish Potato Famine of the mid 1800s and its associated mass emigration. Though often attributed to a "fungal"[76] blight, this saga in Irish history was not due to the failure of potato crops but to the theft of the many *other* vegetables and meats that the Irish produced by troops of British colonizers. While potato crops were wiped out at this time due to heavy rains and the infection of *Phytophthora infestans* they brought, the loss was only a small percentage of the country's self-sufficient food system. And yet, contemporary mycophobia has enabled this lie to seep into history books unquestioned, effectively perpetuating a fungal fear while covering up a forgotten assault on the Irish people.[77]

Adding to the negative conceptions of fungi are the more recent attempts at their weaponization. The Soviet and U.S. militaries have done extensive biological weapons research into the delivery of fungal blights, most notably with Wheat Stem Rust (*Puccinia graminis* var. tritici, or "Agent TX") in the Air Force's anti-crop program. *Fusarium oxysporum* has also been investigated as a mycoherbicide against the culturally important crops of coca, cannabis, and opium poppy crops.[78] Meanwhile, the idea that some day humans or Nature will develop a *Cordyceps*-like fungus that turns humans into the walking dead hangs as a frightening fungal ability that no other organism seems capable of possessing.

In 54 CE, Emperor Claudius was killed by his wife Agrippina the Younger when she soaked a meal of Ceasar's Amanita (Amanita caesarea) *in the juice of the deadly Death Cap mushroom* (A. phalloides), *shown here.*[96]

Along the border of living and dying, mycelia sense and digest, interpret and destroy. More visibly than the bacteria with which they work, the fungi walk between worlds, acting as custodians of the darkness. Some species are so intimately tied to decay that they primarily live and fruit from dead animal parts. These are the *preteiphilous fungi*, typified by the Corpse Finder mushroom (*Hebeloma syriense*). Once found fruiting from a buried box of baby's bones, this necrophilic fungus is often used in forensic investigations to detect the corpse of murder victims.[79] The *myco-corrosion* of fungi threatens every relic of history, from 35,000-year-old cave paintings in Lascaux, France, to all glass, concrete, plastic, wood, ceramic, rock, and metal objects created today. The dry rotting fungi *Serpula lacrymans, Phellinus megaloporus, Coniphora puteana, Fibroporia vaillantii*, and *Meruliporia incrassata* can crumble human structures in a matter of years, just as various polypores regularly destroy ships, mines, and bridges, and make 15–20% of lumber unsellable. With its preference for corroding railroad ties, the Train Wrecker (*Lentinus lepideus*) has been suspected for causing major derailments in the past. The USDA was so afraid of this fungus that the closely related Shiitake mushroom was banned from importation until 1972. Today, the lichen *Dirina massiliensis* f. sorediata is rapidly dissolving limestone monuments in urban deserts, just as *Coprinopsis cinerea* can degrade death-defying prosthetic hearts[80] and the Kerosene Fungus (*Amorphotheca resinae*) feeds on jet fuel, causing planes to crash.

In the end, fungi will destroy everything that humans have ever created. Driving monuments to the Earth, it is the fungi that will carry life through the cruelest acts that humans perpetrate against Nature and redefine spaces for plants, animals, and the wild to thrive. Fungi set the time limit on human productions, a law resisted by past civilizations that built their greatest monuments from stone. To gain time, ancient people had to fight the unstoppable force of fungal decay. Thus, as the ultimate harbingers of death, fungi not only symbolize the impermanence of an individual, but also the fragility of one's way of life, with each hypha slowly decaying the hourglass of a culture's legacy.

The aflatoxins produced by Aspergillus flavus *and* A. parasiticus *are some of the most carcinogenic compounds known on the planet. Aflatoxin B_1 induces liver cancer at concentrations below 1 mg per kg of body weight. These fungi grow on stored grains and beans and are a major contaminant of coffee.*

And, yet, though these realizations were likely had by many people of the past, mycophobia cannot be dismissed as only the outcome of thanatophobia, the fear of one's death, or even the fear of losing one's culture. Many past and present societies held a reverence for death, often embracing it as a natural, integral, and sacred part of life. For the Haida people of southwestern Canada, this was expressed in part by the burial of deceased shamen with figurines of Agarikon that were carved into shapes meant to capture and protect the spirit of the departed. To risk or sacrifice one's life is seen in many societies as a great honor, and the mark of emotional or spiritual maturation. Confronting death directly and embracing its inevitability can be quite positive and can assist a person in their self-development. To assume that a mycophobic culture was afraid of death in its exoteric form may be erroneous, nothing more than the projection of a researcher's own beliefs and fears.

If it was not the physical acts of death and destruction that led to a fear of fungi, then perhaps it was what death and the mushroom represented. Death is not just the loss of one's body, but also the destruction of one's sense of self—one's ego. To face death is to humbly surrender one's understanding of existence and, in effect, admit that one can never understand the universe in its

*(Left) Dry Rot Fungus (*Serpula lacrymans*) rhizomorphs degrading masonry.*

*(Center) The Desert Puffball (*Podaxis pistillaris*) breaking through asphalt. The similar appearing Shaggy Mane (*Coprinus comatus*) is known to do the same.*

(Right) Lichens degrading a tombstone.

entirety. Such an act is in direct contrast to the ego-based mind of everyday awareness that is constantly working to confirm its assurances, often by avoiding what it does not understand. To those incapable of facing the death of their ego, the mysterious mushrooms would readily be avoided for their small reminders of life's unknowable secrets.

Maybe this is why so many ancient cultures only permitted the elite and priests to touch fungi, so powerful was their wisdom. In contrast to the control systems of states and religions, access to mysteries can be obtained through direct and personal means of working with fungi. As covered in Chapter 12, this class-based segregation was likely also an attempt to cover up the knowledge gained from psychoactive fungi, a power reserved for the elect and hidden from the unfit. If this was the case, then to control the lessons of the fungi, the elite may have created an artificial fear around them and intentionally limited access to their study.

As civilizations become increasingly complex, this fear of the unknown likely extended from death to the mysteries of Nature. As author Leonard Shlain describes in his book *The Alphabet Versus the Goddess,* this may have occurred around the time writing systems first developed millennia ago. In many cultures, as writing came to replace direct experience and symbolic thinking, a rift arose that led to an increasing degree of disconnection between humans and the natural processes in their environment. As a part of this, the logical, aggressive, and mechanistic modes of thinking that writing requires came into prominence. And in return, the contemplative, symbolic, receptive,

and generative qualities of life—what is known as the feminine principle, or *yin*—became increasingly suppressed.[81]

Looking at industrial cultures today, the *yin* state seems antithetical to the notion of civilization as we know it. Modern civilization implies predictability and stagnation, but Nature is mutable and ever-changing. Industry demands standardization and segregation—Nature curves and connects. For the first civilizations that significantly distanced themselves from natural processes, these dichotomies would have caused a form of cognitive dissonance. One outcome of this would have been attempts to control Nature's untamable wildness, a child-like demand for superiority meant to cover up rising confusion and frustrations. As cultures became increasingly separated from Nature, this internal and unspoken conflict in the human spirit would have led to a pervasive and unnamable angst that could only be expressed through increased aggressions against the world. Under this imposition, the unpredictable fungi became a target. Fungi are the antithesis of civilization, born of wild mycelium that is free of social constraints and defiant of imposed hierarchies.

As mechanistic cultures became increasingly removed from the natural world, Nature became a reminder of that detachment's debilitating effects. In contrast to the ease and comforts of civilization, Nature is dangerous, a place where anyone lacking the skills to hunt animals or identify plants can fall into unforeseen death traps. To the civilized, the wild reminds one of their fragility, an unacknowledged weakness that the masculine mindset seeks to disavow. All reminders of this vulnerability were to be covered by constant assertions of strength and power. To this fear fell the death-tinged mushrooms and their ability to swallow one whole in the fairy ring of life's cycles.

Left unaddressed, these fears sunk deep into the mindset of increasingly abstracted civilizations. As demands for performance, conquest, and stimulation drowned out the *yin* in Nature, the stillness that fungal observation requires became increasingly removed from life. The internal self was lost in the extroversion of the ego, leading to a fear of being alone, the ridicule of introversion, and the loss of Nature-based spirituality. As an outcome, mycophobia was entrenched as not only a fear of the mystery that fungi harbor, but also of the state of being required to align with that mystery.

Thus, to fully address and overturn a fear of fungi, a mycophobic culture must overturn the suppression of these qualities of life. To be reconnected to fungi requires a full embrace of all that Nature presents: positive and negative, light and dark, known and unknown. Through such a reintegration, new cultures can be recomposed from the elements of the old and regenerated into a healthier form. This applies to the whole of a culture, as well as to every individual invested in its redefinition.

Dark and witch-associated fungi

Bulgaria inquinans
Craterellus cornucopioides
Elaphomyces granulatus
(Hexenpizet [witches's saliva] in Austria and Germany)
Exidia glandulosa
(Black Witch's Butter)
Geoglossum glutinosum
Sarcosoma mexicana
Taphrina betulina
(Witch's Broom)
Tremella mesenterica
(Witch's Butter)
Urnula craterium

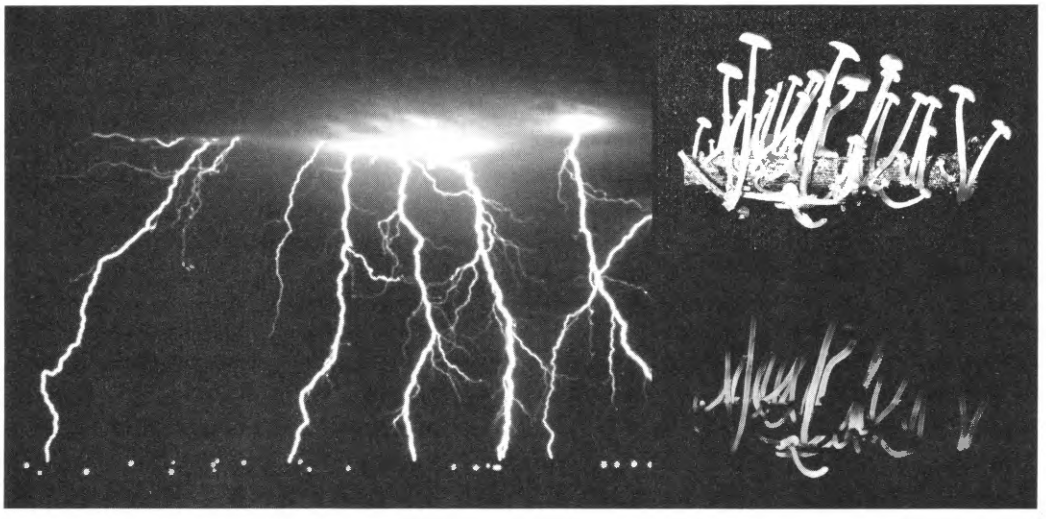
Ultimately, the fungi represent not death, nor loss, nor decay, but the subsequent rebirth that destruction offers, both physical and philosophical. This principle is expressed by many fungi. In sites once devastated by burns or lava flows, the *phoenicoid fungi* of the *Anthracobia* are often found rising like mythic birds of fire, only to later quickly die back and become the initial reserves for seeds that give birth to an entire forest.[82] Beyond the edge of the solemn fairy ring, grass is distinctly brighter, while inside this perimeter it is brown and dead due to having given its life to the expanding mycelium. Expanding ever outward, fairy rings shine from the light of the recently deceased and never grow back. To the ancient Egyptians, this duality was recognized through the use of the lichen *Pseudevernia fufuracea* as both a stuffing for mummy corpses and as an ingredient in bread, a pillar of their diet.[83]

For some cultures, this regenerative quality was recognized in the relationships between fungi, light, and life-providing fire, as found in the sacred fungal smokes and smudges noted earlier and with the internal fire of bioluminescent fungi. More than 75 Basidiomycota and 1 Ascomycete produce illuminating fruit bodies (e.g. *Panellus stipticus* and *Xylaria hypoxylon*), spores (*Roridomyces roridus*), or "foxfire" rhizomorphs (*Armillaria spp.*). This cold light is due to the presence of luciferase, the same chemical responsible for the glow of fireflies and anglerfish from the deep sea. Other fungi seem to emit a more subtle light. When wrapped in black paper, the stinkhorn *Phallus impudicus* emits an invisible luminescence that can develop a photographic plate overnight.[84] Many other fungi likely also glow in ways that humans cannot perceive. Perhaps such associations underlie the common name for the white jelly fungus *Tremella nostoc*, Sky Fall, and its long believed origin from shooting stars.

Fungal fire is also found to have a common connection with the creative powers drawn from lighting, a fire in the sky. Plutarch (46–120 CE) said that truffles arose when the generative fluids in thunder mixed with heat and pierced the earth in a flash of lightning.[85] Likewise, Anthenaeus (c. 200 CE) wrote that the quantity and size of truffles were influenced by the number and force of thunderclaps, a view still held by the Bedouin in the Negev desert. Pliny the Elder (23–79 CE) called truffles *vittium terre*, and said that they are the product of lightning bolts. In the 1811 Chinese text *The History of Mushrooms*, Ishiwara Gusha notes three fungi directly associated with lightning: *lei-ching t'an* ("thunder-aroused mushroom"), *lei-sheng chun* ("thunder-peal mushroom"), and *lei chun* ("thunder-mushroom"). And in New Zealand, the Maori word for "thunder" and "female ancestor" (*whatitiri*) was used in the name for *Clathrus cibarius*: *tutae whatitiri*. In the Latin American language Quiche, *Amanita muscaria* is called *kakuljá* ("lightning bolt").[86] In the Mayan creation story of the Popol Vuh three kinds of *kakuljá* are mentioned: *kakuljá hurukan* ("lightning bolt one-leg"), *chipi kakuljá* ("dwarf lightning bolt"), and *raxa kakuljá* ("green lightning bolt").[87] Similar lightning-mushroom associations were made amongst people in Rome, Germany, Madagascar, the Philippines, France (*Boletus satanas* and *B. luridus*), Italy (*trun*, "thunder-mushroom," for *Lactarius sanguifluus* and *L. deliciosus*), Iran (where mushrooms are born from the sky deity *Mama*, "grandmother"), India (*Phallus spp.* and puffballs), Afghanistan ("earth meat," for *Morchella spp.* and *gokluk* for *Coprinus comatus*), Uzbekistan (*qoza-qarni*, "baby lamb's belly" for *Morchella spp.*), Tajikistan (*Xorč* for *Pleurotus fossulatus*), Tibet (*ser sha*, "yellow flesh"), Kashmir (*kana-guch*, "ear-mushroom," for *Morchella spp.* and *hēdur* and *hēnda* for agarics), Luzon (*payungpayungan kulog* for *Termitomyces albuminosus*), and Japan (*raigan*, "thunder balls," for *Omphalia lapidescens*).[88]

In the Haida people's story of the creation of woman, Fungus Man and Raven travel in a canoe searching for female genitalia.

As this connection between fungi and creation deepened, so too did its association to fertility, rebirth, and the feminine principle. For some cultures, this was symbolized through associations with fungi and the honeybee, an insect long regarded as a symbol of immortality and resurrection. Nordic legends stated that bees emerged from an enchanted, subterranean world that they shared with fairies. For the Nordic people, bees possessed prophetic virtues and by watching their flight, it was believed one could predict the future. In Scots Gaelic, the word for bee (*beacan*) also means mushroom.[89] Across Ireland, there are beehive-shaped stone huts sunken into the earth—womb-like chambers that have been used for centuries as sweat houses potentially during traditional rituals that incorporated *Psilocybe semilanceata* mushrooms.[90] In the Tassili plateau of northern Algeria, the oldest representative art of mushrooms depicts a dancing human figure with the head of a bee and a body radiating mushroom-shaped projections. To the ancient Egyptians, bees came from sacred bulls, a relationship reminiscent of the psychoactive *Psilocybe* mushrooms that grow from cow dung. For many cultures, the bee represented the Mother Goddess due to its ability to pollinate plants and transmute nectar to sweet, fire-colored honey, just as fungi convert dead material to fruit bodies and the soil that bears new life.



(Left) The mycelial strikes of fire in the sky.

(Right) The cold light of bioluminescent fungi is produced by the compound luciferase.

In other cultures, mushrooms have also been connected to the toad, itself an amphibious and at times hermaphroditic creature[91] of water and Earth, and thus a symbol of fertility and the Mother Goddess. In some Balto-Finnish dialects the word *sampo* stands for "mushroom" as well as "toad." The Delaware tribe of North America believed that mushrooms grew from frog spawn, while in Mesoamerica, Centeotl was the patron of fertility and took the form of a frog. Here, frogs were considered spirits of rain. In Welsh, inedible fungi are called *caws llyffant* ("toad's cheese") and *bwyd-y-llyyfant* ("toad's foot"). Despite the fact that toads are rarely seen in Ireland, the Gaelic name for wild fungi is *bolg losgain* ("frog's pouch"). Similar connections are found in countries around the world, including Denmark (*paddehat*, "toad's hat"), Norway (*paddehatt*, "toad's hat"), Sweden (*puggehattar*, "toad's hat"), France (*kabell toussec*, "toad's cap," and *escabeau de crapaud*, "toad's stool"), Netherlands (*paddestoelen*, "toadstools"), Slovakia (*žabací huby*, "toad-mushrooms"), Ukraine (*zhabjachyi hryb*, "toad-mushrooms"), Sudan (*hegba-mboddoh*, "toadstool"), Nigeria (*korowal-pabi*, "toadstools"), India (*rote putka*, "toad soul-plant"), Japan (*gama-no-koshikake*, "toad's stool"), Basques (*xapo-perretxiko*, "toad mushroom," and *amoroto*, "toad-like thing" for *Amanita muscaria*), and Guatemala (*holom ixpek*, "toad's head").[92]

In many countries, especially in Europe, mushrooms and toads were directly linked to female witches and their knowledge of herbs, potions, and magic. Toads were often considered the familiars, or spirit helpers, of witches. To alchemists, toads were said to hold special healing powers that derived from a "toadstone" (*crapaudina*) in their heads. Up until the 19th century, English women would gather fungi under the full Moon and cook them with a live toad and spring water to create a love potion.[93]

To the ancient Chinese, the toad was an embodiment of *yin* forces and thus intimately tied to the Moon, itself a symbol of the darkness and internal contemplation of *yin* energy. In Chinese mythology, the craters of the Moon do not form a "man in the Moon," as commonly interpreted by Westerners, but a rabbit and three-legged toad. This Moon-toad often appeared as a mythical creature in ancient India, Nepal, and Japan. In China it was sometimes depicted with Reishi growing from its forehead.[94] In ancient Greece, the toad was the emblem of Aphrodite, the goddess of sexual passion who was strongly connected with Venus. And in Egypt, the toad-headed goddess Heket (Heqet) was aligned with water, renewal, birth, conception, and fertility. She was the psychopomp: guide for the recently deceased and wayshower to the land of the dead.

Hecate, the triple-faced Moon goddess.

Heket may have served as the template for Hecate, the Greek crone goddess of crossroads, mysteries, witchcraft, death, decay, and regeneration. Often portrayed as the torch-bearing Moon goddess, Hecate bears a headdress of stars that light the way into the darkness of inner being. She is triple-faced, giving her the ability to look in all directions and bring great vision derived from a long life's wisdom. Her alternate is Baubo, a stomach-faced goddess referred to as a "she-toad." Also known as the Queen of Ghosts and Mother of Witches, Hecate brought the seeds of new life out of the underworld and into the composting heaps of decomposing forms. It was she who led Eleusian participants into the underworld. And on November 16th, the Night of Hecate during the Mysteries, animal sacrifices would be performed and Hecate's Supper consumed, often featuring honey and mushrooms as central elements.

Ultimately, to fear fungi, death, and the recompositions that they create is to suppress the generative female qualities that the Queendom represents. Much like the suppression of fungi, the global oppression of women has long been noted and yet its origin remains unclear. To the psychoanalyst Karen Horney, oppression against women was primarily born long ago from men's jealousy of the womb's ability to create life. To Horney, attempts to keep women and Nature under control stem not from a simple need to dominate, but from a desire to control the very act of creation. So it is that we find the male-dominated, genetic-focused approach to modern mycology owing its origins to the theft of knowledge from herb wives and witches of the past.

To the psychologist Carl Jung, the suppression of the feminine aspect in one's psyche—what he referred to as the *anima*—invariably results in the conflation of its opposite: the masculine principle, or *animus*. When affecting the majority of individuals in a whole society, this imbalance would subsequently lead to the creation of an animus-dominated culture, one that is predominantly violent, aggressive, and non-emotive. Such cultures would outwardly be deterred from developing

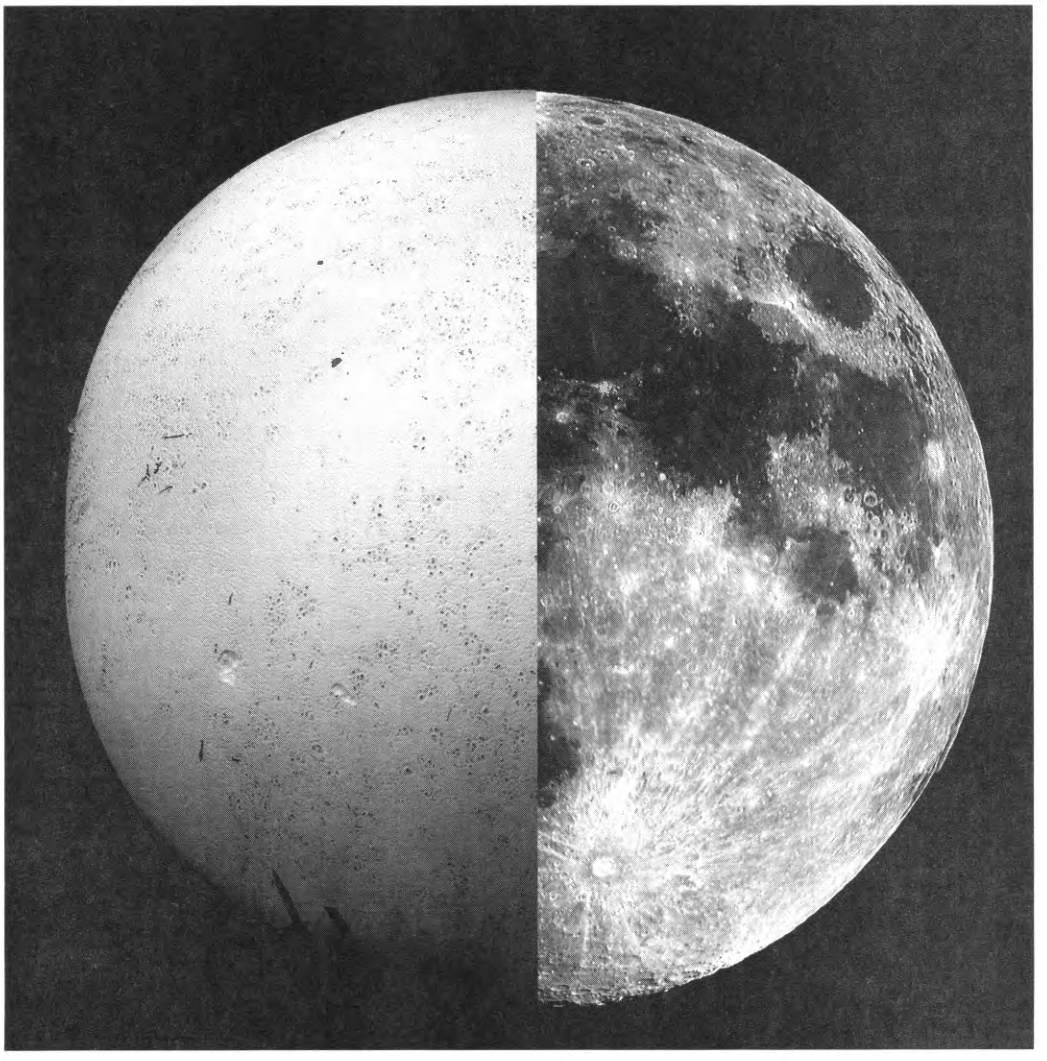
a deep relationship with fungi. Rather, they would seek to hide, erase, and pave over any healing and regenerative reminders of Nature's abundance, an unnatural desire increasingly reflected in the array of upheavals facing the world today.

For ancient people aware of the powers contained in the fungi, these children of darkness must have been one of the grand symbols of life's mysteries. Some cultures likely retained this connection, as seems to have occurred to some degree with the Maori and Chinese. Conversely, much of this memory seems to be lost among modern Western civilizations that have forgotten the importance of supporting their environment and facing the fallout of the world's dark ecologies.[95]

Grave imbalances always demand and bring about change, as fungi remind us. Perhaps this is why mycology has started to obtain greater public awareness within the last decade. During some of the most challenging times of recent centuries, it is now that humans are being offered the greatest opportunities to ally with their long forgotten kin and find connections that lead to a new beginning. Whereas the world has been so *yang* oriented for millennia, perhaps the increased awareness around mycology is the outcome of an ancestral need in humanity to balance the qualities of life and allow its creative capacities to thrive. Developing this relationship with fungi is possible, if not deeply needed, but only when one takes the time to observe them, contemplate, and learn.

Its father is the Sun, its mother the Moon; the wind has carried it in his belly; its nurse is the Earth. Its power is complete when it is turned toward the Earth. It ascends from Earth to heaven, and descends again to the Earth, and receives the power of the higher and lower things. So will you have the glory of the whole world.

—Hermes Trismegistus, Tabula Smaragdina



When the Moon is at the full
Mushrooms you may freely pull.
But when the Moon is on the wane
Wait ere you think to pluck again.

—Traditional rhyme of Essex, Britain

Fungal HERstory: How Women Shaped Mycology

By Mara Penfil and Fern Katz

The study of mycology first formed in the wombs of women. Though the knowledge was shared with every child as they matured, it was often the women of history who carried on the responsibility of harvesting wild fungi to feed and heal their families. By practicing and maintaining these skills throughout many generations, women around the world possessed the richest and most comprehensive understanding of the taxonomy, biology, and ecology of local fungal diversity. Women were the original and primary ambassadors to the world of fungi.[97]

It is only in the last few centuries that the study of fungi has become dominated by men. The founders of modern mycology, Carolous Clusius (1526–1609) and Franciscus Van Sterbeek (1630–1693), were perhaps the first instigators of this shift. However, their knowledge did not come from personal experience. Most of their research came from conversations with folk-women in the marketplaces of Eastern and Central Europe. Here, these early authors would talk with the women knowledge-keepers directly in an effort to gather traditional mycological information, and then rebrand it as their own work.[98] The famous biologist Carl Linnaeus (1707–1778) was also known to learn about fungi and plants directly from herb-wives and medicine-women of the marketplace.[99]

Many studies, outlined in detail by Frank Dugan in his book, *Conspectus of World Ethnomycology*, indicate that these men were just a few of the many seekers who sought mycological, and more broadly botanical and medicinal, knowledge from women.[100] Dugan writes,

> *"Recognition of such interactions between famous (and nearly always male) pioneers in science and medicine and lay folk reflects the rather recent tendency for the historians of science to credit the achievements of peasant farmers and working people in laying the foundations of science..."* [101]

During the European Renaissance (14th–17th century), the scientific library continued to add information gathered from women knowledge-keepers.[102] In these works, the culinary benefits of fungi were often emphasized, as were their medicinal applications. Simultaneously, the practice of medicine throughout Europe was shifting from its traditional roots to an official state recognized profession. This shift began a prohibition against the unauthorized practice of medicine—much of which was done by traditional practitioners, such as the impoverished women from whom the medical knowledge was gathered. In time, women who chose to continue to treat patients in traditional ways—or who were merely suspected of doing so—were labeled as witches and accused of placing curses on people. And, for some reason, these women were commonly associated with mushrooms, a link that was frequently perpetuated through folklore.[103] For example, Baba Yaga was a female witch who, in Baltic and Slavic contexts, was regularly connected with mushrooms.[104]

Masked as a cleansing of evil spirits, the witch hunts that plagued Europe and parts of North America in the 15th–17th centuries not only displaced women from their traditional roles, but slaughtered them en masse, with current estimates counting the death of tens of thousands of women around Europe. As these women were lost, so too fell an immeasurable amount of undocumented fungal and botanical knowledge.[106]

Both men and women were targeted during the witch hunts, although the mortality rates for women are significantly higher—in certain places, up to 95% of those murdered were women.

A century after the end of the witch hunts, women were still not allowed to formally enter scientific fields, including that of mycology. One famous account is of Beatrix Potter (1866-1943), the author of the children's book *Peter Rabbit*. Before becoming an author, Potter was known for her deep love for fungi. Early on in her life, Potter created many beautiful and accurate mushroom monographs[107] that are still used today to help others with identifying species. She also wrote, "On the Germination of the Spores of the Agaricineae," which she submitted to the Linnean Society in 1897. However, as a female, the Society did not allow her to present her paper, and instead it was presented by a man. Recently, Potter's paper has been re-evaluated and recognized for its historical value.

The pivotal discovery of the use of agar-agar for microbiology and mycology work is also credited to a female scientist. In 1881, Fanny Hesse suggested the use of agar to her lab partner and

husband Walter while they were working as lab assistants for the infamous "father of microbiology," Robert Koch. When the use of agar was found to be superior to other gelling agents, Koch claimed the discovery as his own and put it to use to further both scientific research as well as his career.[108] Neither Fanny nor Walter were given any recognition for this discovery, while Koch's name rose to fame. It was not until recently that the Hesses' were given the credit they deserve for their discovery of uses for this ingredient, which has significantly contributed to many of the advances in mycological studies over the last century.

*The link between women, witches, and mushrooms can still be found lingering in mushroom taxonomy today. An old folklore tells the story that, inside the homes that a witch had placed a curse, the orange jelly fungus Witches Butter (*Tremella mesenterica*) would mysteriously appear.*[105]

Flora W. Patterson (1847–1928) was the first female plant pathologist to work for the United States Department of Agriculture (USDA) and later went on to become the Department's Mycologist in Charge of Mycological and Pathological Collections. Just two years prior to her employment with the USDA in 1895, Patterson had attempted to complete her studies at Yale University. To her dismay, Yale was not admitting female students at that time, so she attended Radcliffe College and received formal mycological training while working as an assistant in Harvard University's Grey Herbarium. During her nearly three decades with the USDA, Patterson identified many novel fungal infections while also developing a means for successfully eradicating several detrimental blights.[109] Moreover, Patterson expanded the U.S. National Fungus Collection by over 90,000 specimens, an effort that benefits the scientific community to this day.[110] During her career, three other female mycologists were hired to work with her.

How many "fathers" of science are recognized in modern history? And in contrast, how many "mothers"?

Though women in many countries today have the freedom to work in scientific fields, their presence is still in the minority. There are currently no statistics on how many women practice in the field of mycology, but looking at science more broadly, only 30% of the world's researchers are women.[111] Despite making up nearly half of the U.S. workforce and half of the college-educated workforce, women in the U.S. hold fewer than 25% of jobs in STEM fields (science, technology, engineering, and math).[112] Only 11% of the top academic science positions are held by women in the European Union, and women are awarded less than 3% of the Nobel prizes in the sciences.[113] Possibly at the heart of this is the perception that women do not have the skills for science, an unfounded stigma that is perpetuated and spread throughout many modern cultures. One recent study examining this subtle phenomemon of oppression found that 67% of Europeans and 93% of Chinese respondents do not believe that women are cut out for the sciences.[114] Even Tim Hunt, a Nobel Prize-winning biochemist, has stated that women cause "trouble" in the lab.[115]

Throughout the 18th and 19th centuries, women were commonly depicted in art with, or foraging for, mushrooms. This relationship is still made by artists of today and artwork portraying these themes can be found in abundance online.

"Universal Veil" by Tiffany Bozic. 36" x 46" acrylic on maple panel, 2014 (original in color). Printed with permission.

Math and science originally come from the goddess traditions of ancient Egypt. In Egyptian mythology there were the goddesses Ma'at and Seshat who together, along with the God Thoth, represented the foundational concepts and principles that are still known in these fields today. Ma'at was the Goddess of truth, justice, and divine wisdom who brought the universe into order from chaos at the beginning of creation. Her name is the root of the word "mathematics." Seshat was the Goddess of wisdom, knowledge, and writing. She was a master in the areas of architecture, astronomy, astrology, building, mathematics, and surveying.

Despite the gender-based barriers that persist to this day, many women can be found working in the field of mycology, whether in higher education, innovative businesses, or as a part of community-based organizations. Kathie Hodge of the Cornell Plant Pathology Herbarium focuses her work on fungal biodiversity, aiming to expand our collective knowledge of fungal species, especially in relationship to fungal pathogens of insects. Hodge is also the founder of the Cornell Mushroom Blog, which she uses to demystify molds and mushrooms in the public eye and teaches her students to do the same. Sue Van Hook, chief mycologist of New York based company Ecovative Design, uses her skills in taxonomy, cultivation, and education to help the company develop sustainable alternatives to plastics for packaging and building materials. Giuliana Furci, a Chilean environmental and fungal activist, is the mastermind behind the Fungi Foundation, an organization that promotes fungal conservation in Chile. With the central notion that fungi are critical to the outcome of conservation at large, Furci and her team are committed to the protection of fungi by advocating for change in public policy around the world. Chido Govera, founder of the Future of Hope Foundation in Zimbabwe, Africa, is committed to empowering young orphans and women in her region by offering mushroom cultivation education and support to those interested in starting their own mushroom farms.

Since before the founding of modern mycology by men like Carolous Clusius and Franciscus Van Sterbeek, women have maintained an in-depth and fertile understanding of the Fungal Queendom. And though these are just a small sampling of the dedicated women mycologists in the world, they are living proof that women continue to be critical holders and transmitters of mycological knowledge. Identifying influential women and projects like these in the public domain, and within the context of our own lives, is essential for creating a mycelial network of support and mentorship for the future generations of women within the global mycological community. People of all genders and body types are encouraged to support the continued rise of women in a new era of the fungal revolution.

To help strengthen the community of women in mycology, science, and society at large, we must speak out against gender adversity in every facet of our lives. Outlined here are some ways that you can take action:

- **Get involved** with an organization like a local mycology club, a radical feminist group, a political advocacy group, a sexual assault support group, or anything in between. The role you take depends on your skills and comfort levels and it will likely change over time. If organizations are limited in your area, consider starting one.
- **Become media literate.** The media heavily shapes how we view ourselves and the world around us. Mass media poorly depicts women, and these harmful messages become internalized by the consuming population. Mass media also has a preference for highlighting white male experts in various fields of science and technology, creating damaging stereotypes about who the practitioners of these fields are. Being able to deconstruct harmful media messages is a great way to learn how to reconstruct positive ones.
- **Break the silence** and talk about your experiences with gender adversity. This can be done in a number of ways, from conversing with a small group of people to utilizing the broader outreach of media.[116] Sharing your story can help create the space needed to heal and inspire others to release their stories as well. The strength of a united front can fight oppression; no longer shall we be convinced to battle against each other to rise to the top. Together, we can identify patterns of abuse in the home, the workplace, on the streets, and anywhere else it exists. As the global campaign One Billion Rising[117] outlines, we must identify the patterns and intersections between gender violence and inequality with poverty, racism, war, environmental destruction, capitalism, imperialism, and patriarchy in order to identify effective solutions to be put into action.
- **Live the life you want to live.** Lead by example and pave the path for our children's children to grow and follow.
- **Keep making trouble** because sometimes no one listens until you spill a little milk.

Part II

Connection

Chapter Four

Seeing Fungi

Everyone has to seek nature for himself. —Masanobu Fukuoka

I wish it to be wholly understood what I have become of Nature and what Nature has become of me. If you wish to understand me only passably, you must know how Nature found me and I found Nature during our first encounter; then you will have the history and the exposition of my perceptions. —Goethe

If you think you are a mushroom, jump into the basket. —Russian proverb

For those who seek, so shall they find the fungi being. Regardless of the season or the extent of human settlement, the molds, yeasts, mycorrhizal fungi, endophytes, saprotrophs, and lichens of the world offer their presence in nearly all habitats and climates. Just as many people and cultures have learned about the world from working with plants, animals, or landscapes, so too can developing relationships with fungi offer novel means for inspiration. Silently and subtly, they await discovery by all who pause to look.

Historically, humans have foraged for only a small number of edible and/or medicinal mushroom species. But as the importance of the various types of fungi has become increasingly recognized in recent years, mycologists are now afforded a range of methods for discovering wild fungi. At times, the most profound moments come not from tracking and naming one fungus or another, or from the temporary thrill of finding a "choice" edible species. Rather, when the hunt is deeply embodied, the seeker will be provided with a much more timeless perspective on fungi: one filled with a constant appreciation for the multitude of their forms and habits. To draw toward the fungi is to be drawn into their webs. The result is a hunter left not just with a unique means for interpreting the world, but also a chance to realign to forgotten rhythms and rewild within the entwined ecology of a place.

To Call a Mushroom by Any Other Name

One of the easiest means to experience fungi is by encountering their larger forms: the mushrooms. Recognizing the numerous in-depth mushroom field guides that have been produced over the decades, this chapter is not meant as a comparison to those fine works, but to lower the learning curve for novice hunters.

The first step to hunting mushrooms is determining what species are likely to be fruiting in your current climate, region, and season. Local field guides are helpful here as they often have regional fruiting windows for a given species, which can vary significantly between watersheds. In general, most edible species appear around the beginning of the cooler, rainier times of year, but many edible, medicinal, and ecologically important species can be found year-round.

Written in 1245 CE, The Mycoflora *by Chen Jen-yu discusses the identification and preparation of 11 mushroom species.*

Once you determine which species may be fruiting, the next question is to consider which you desire to hunt. If you cannot choose just a few that are most appealing to you (or if they all appeal to you), simply go out into the woods and fields to see what you find. If you're starting out, only pick a small number of relatively distinctive species. This will help ease the identification process later on.

For a more focused approach, select a couple of species that you are interested in and then locate an area that matches their preferred habitat. Common niches include pastures, fields, burned areas, old growth forests, sparse woodlots, disturbed or compacted ground, melting snowbanks, deserts, riparian zones, and sand dunes. Some species grow in several of these niches, while others are endemic to very small zones. In wooded areas, the types of trees and other flora present have a direct influence on the fungal diversity. Many mycorrhizal mushrooms are only found in association with just one or several tree types. The elevation of your hunt matters, too. As a season progresses, the required fruiting temperature for a species may move up or down a mountain, depending on whether it's a spring or fall mushroom, respectively. The season of fruiting, plant associations, and ideal elevation for mushrooms can all vary geographically.

A good local field guide or mentor is invaluable. Mycological societies are especially rich in local hunting knowledge, including which local species are poisonous. Experienced hunters learn the fruiting patterns of local species and often anticipate where and when to find their favorite fungi fruiting. For those most attuned, this relationship can become a sort of sixth sense, a knowing that they *are* out there. This process takes time and commitment, but its reward, like developing a solid foundation for a long-term friendship, is in the nourishment that comes in the years that follow.

There are plenty of bold mushroom hunters and plenty of old mushroom hunters. But there aren't a lot of old, bold hunters.

—Anonymous

What About Poisonous Mushrooms?

To enter the mushroom hunt, one must always acknowledge the respect commanded by the various toxic metabolites produced by fungi. A single misidentified poisonous mushroom can lead to significant organ damage, complete liver failure, or death. However, this fate can readily be avoided by learning to identify the fatal species before all others.

This does not mean one must learn to recognize every toxic species in their area, but to at least recognize the genera that are responsible for most poisonings. Of the estimated 150,000 mushroom-forming fungi in the world, only around 400 are thought to be toxic.[1] In North America, only 1-2% of the approximately 5,000 mushroom species are significantly toxic and only around 30 species are lethal. Most of these poisonous fungi are in the genera *Amanita, Cortinarius, Galerina, Gyromitra,* and *Inocybe.*

All mushrooms are edible, but some only once.

—Croatian proverb

There is no "rule of thumb" or magical way of knowing if a mushroom is poisonous. It is only due to unfortunate experiences held by countless mycophagists that today we know which species should not be eaten. Thus, before anyone eats a mushroom, they must be absolutely positive of its identification. This includes foreign mushrooms, which can look similar to familiar edibles from one's home country.

Caution should also be used when collecting mushrooms that are growing solitarily or in scattered groups. Two mushrooms growing a few centimeters apart that look similar may actually be from completely different genera. A classic example of this concurrence is with the psychoactive *Psilocybe* mushrooms and the deadly poisonous *Galerina* fruit bodies. These mushrooms are known to grow so close to each other that they touch! In this example, the quickest means for telling the two apart is with a spore print.[2] If you have any doubt that two mushrooms in a patch are the same species, be sure to place them into individual bags and later identify each on their own.

Ancient treatments for consuming toxic mushrooms included various emetic concoctions of pungent mustards, bird dung, and vinegar.

The North American Mycological Society receives around 70 legitimate calls of human mushroom poisonings per year and around 30 for animal poisonings. The most frequent form of mushroom poisoning is not fatal but produces a serious bout of gastrointestinal (GI) distress. Symptoms of such poisonings may appear within 20 minutes to 4 hours of ingesting the mushrooms and include cramps, nausea, vomiting, and diarrhea. Hospitalization may be required in severe poisonings, but in most cases treatment is largely supportive. Only about 1% of poisonings are fatal. See Appendix C for more information on deadly mushroom toxins and their common symptoms.

Popular Edible Mushrooms

			Approximate Fruiting Season												
			Jan. - Wolf Moon	Feb. - Snow Moon	Mar. - Worm Moon	Apr. - Pink Moon	May - Flower Moon	June - Strawberry Moon	July - Buck Moon	Aug. - Sturgeon Moon	Sept. - Harvest Moon	Oct. - Hunter's Moon	Nov. - Beaver Moon	Dec. - Cold Moon
Agaricus	*arvensis*	Horse Mushroom	●	●	●	●		●	●	●	●	●	●	●
	augustus	Prince	●	●		●	●	●	●	●	●	●	●	●
	bernardii	Salt-Loving Mushroom	●	●				●	●	●	●	●	●	●
	bisporus	Button Mushroom					●	●	●	●	●	●	●	
	brunnescens	Button Mushroom	●	●	●	●	●	●	●	●	●	●	●	●
	bitorquis	Spring *Agaricus*	●	●	●	●	●				●	●	●	●
	campestris	Meadow Mushroom						●	●	●	●	●	●	●
	crocodilinus	Crocodile *Agaricus*			●	●	●				●	●	●	●
	fuscofibrillosus	Bleeding *Agaricus*	●	●							●	●	●	●
	haemorrhoidarius	Bleeding *Agaricus*	●	●							●	●	●	●
	subrufrescens	Almond Mushroom	●	●							●	●	●	●
Agrocybe	*aegerita*	Pioppino			●	●	●	●	●	●	●	●	●	
	preacox	Spring *Agrocybe*			●	●	●	●	●	●				
	putaminum	Mulch Fieldcap							●	●	●	●	●	●
Albatrellus	*ovinus*	Sheep Polypore	●	●				●	●	●	●	●	●	●
	flettii	Blue Knight	●	●							●	●	●	●
Aleuria	*aurantia*	Orange Peel Fungus	●	●					●	●	●	●	●	●
Amanita	*calyptrata*	Coccora	●	●							●	●	●	●
	casarea	Ceasar's Amanita			●	●	●	●	●	●	●			
	muscaria	Fly Agaric							●	●	●	●		
	vaginata	Grisette					●	●	●	●	●	●	●	

Popular Edible Mushrooms

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Armillaria	*spp.*	Honey Mushroom						●	●	●	●	●	●	●
Auricularia	*auricula*	Cloud Ear Mushroom					●	●	●	●	●		●	●
Boletus	*aereus*	Queen Bolete	●	●						●	●	●	●	●
	appendiculatus	Butter Bolete									●	●	●	●
	badius	Bay Bolete						●	●	●	●	●	●	●
	barrowsii	Barrow's Bolete						●	●	●	●	●	●	
	bicolor	Two-Colored Bolete						●	●	●	●	●	●	
	edulis	King Bolete				●	●	●	●			●	●	●
	mirabilis	Admirable Bolete								●	●	●	●	
	pinicola	Variant of *B. edulis*								●	●	●		
	regius	Regal Bolete					●	●						
	zelleri	Zeller's Bolete	●	●		●	●	●	●	●	●	●	●	●
Bovista	*spp.*	Puffball	●	●				●	●	●	●	●	●	●
Calbovista	*spp.*	Puffball				●	●	●	●	●				
Calocybe	*gambosa*	St George's Mushroom					●	●						
Calvatia	*gigantea*	Puffball				●	●	●	●	●	●	●		
Cantharellus	*cascadensis*	Cascade Chanterelle						●	●	●	●	●	●	●
	cibarius	Golden Chanterelle	●	●				●	●	●	●	●	●	●
	cinnabarinus	Cinnabar Chanterelle						●	●	●	●	●	●	
	formosus	Pacific Chanterelle							●	●	●	●	●	●

Popular Edible Mushrooms

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Cantharellus	*lateritius*	Smooth Chanterelle						●	●	●	●	●	●	
	subalbidus	White Chanterelle	●	●							●	●	●	●
Catathelasma	*ventricosa*	Mock Matsutake									●	●	●	
Chlorophyllum	*rachodes group*	Shaggy Parasol							●	●	●	●		
Clitocybe	*fragrans*	Fragrant *Clitocybe*								●	●	●	●	●
	odora	Anise *Clitocybe*						●	●	●	●			
Clitopilus	*prunulus*	Sweetbread Mushroom						●	●	●	●	●	●	
Coprinus	*atramentarius*	Alcohol Inky Cap			●	●	●	●	●	●	●	●	●	
	comatus	Shaggy Mane				●	●	●	●	●	●	●	●	
	micaceus	Mica Cap					●	●	●	●	●	●	●	●
Cortinarius	*armillatus*	Bracelet Cortinarius						●	●	●	●	●	●	
Craterellus	*cornucopioides*	Horn of Plenty	●	●	●	●		●	●	●	●	●	●	●
	fallax	Black Trumpet							●	●	●	●	●	
	tubaeformis	Yellow Foot	●	●								●	●	●
Entoloma	*abortivum*	Aborted Entoloma							●	●	●	●	●	
Fistulina	*hepatica*	Beef Steak						●	●	●	●	●	●	
Flammulina	*velutipes*	Velvet Foot	●	●	●	●	●	●	●	●	●	●	●	
Floccularia	*straminea*	Shaggy Stem	●	●				●	●	●	●	●		
Gomphus	*clavatus*	Pig's Ear								●	●	●	●	
Grifola	*frondosa*	Hen of the Woods							●	●	●	●	●	
Helvella	*lacunosa*	Black Saddle	●	●	●	●	●	●	●	●	●	●	●	●

Popular Edible Mushrooms

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Hericium	*coralloides*	Coral *Hericium*							●	●	●	●	●	
	abietis	Conifer Coral									●	●	●	
	erinaceus	Lion's Mane						●	●	●	●	●	●	
	ramosum	Comb Tooth									●	●	●	
Hydnum	*repandum*	Hedgehog	●	●						●	●	●		●
	umbilicatum	Belly-Button						●	●	●	●	●	●	
Hypomyces	*lactifluorum*	Lobster							●	●	●	●	●	
Hygrophorus	*russula*	Russula-Like Waxy Cap							●	●	●	●	●	
Hypholoma	*capnoides*	Conifer Tuft	●	●	●	●	●	●	●	●	●	●	●	●
	sublateritium	Brick Cap								●	●	●	●	
Hypsizygus	*ulmarius*	Elm Oyster								●	●	●	●	●
Laccaria	*amethystina*	Amythest Laccaria						●	●	●	●	●	●	
	bicolor	Bicolored Deceiver			●	●	●	●	●	●	●	●	●	
	laccata	The Deceiver						●	●	●	●	●	●	
Lactarius	*deliciosus*	Delicious Milky Cap			●	●					●	●	●	
	fragilis	Candy Cap						●	●	●	●	●	●	
	indigo	Indigo Milky Cap	●	●				●	●	●	●	●	●	●
	rubrilacteus	Bleeding Milky Cap						●	●	●	●	●	●	
Laetiporus	*spp*	Chicken of the Woods						●	●	●	●	●	●	
Leccinum	*aurantiacum*	Orange-Cap Scaber Stalk						●	●	●	●	●	●	
	insigne	Aspen Scaber Stalk									●	●	●	●
	manzanitae	Manzanita Scaber Stalk						●	●	●	●	●	●	
	scabrum	Scaber Stalk	●				●	●	●	●	●		●	●
Lentinus	*lepideus*	Train Wrecker						●	●	●				

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Lepista	*nuda*	Blewit	●	●						●	●	●	●	●
Lycoperdon	*spp.*	Puffball	●	●	●	●	●	●	●	●	●	●	●	●
Lyphollum	*decastes*	Fried Chicken Mushroom	●	●	●	●	●	●	●	●	●	●	●	●
Macrolepiota	*procera*	Parasol		●				●	●	●	●	●	●	
Marasmius	*oreades*	Fairy Ring Mushroom	●	●	●	●	●	●	●	●	●	●	●	●
	scorodonius	Garlic Marasmius						●	●	●	●	●	●	
Morchella	*angusticeps*	Morel			●	●	●	●	●					
	conica	Morel			●	●	●	●	●	●				
	deliciosa	Morel		●	●	●	●	●	●					
	esculenta	Morel			●	●	●	●						
Phlogiotis	*helvelloides*	Apricot Jelly	●	●				●	●	●	●	●	●	●
Pleurocybella	*porrigens*	Angel Wings									●	●	●	
Pleurotus	*spp.*	Oysters	●	●	●	●	●	●	●		●	●	●	●
Pluteus	*cervinus*	Horse Mushroom			●	●	●	●	●	●	●	●	●	●
Pseudohydnum	*gelatinosum*	Toothed Jelly Fungus	●	●					●	●	●	●	●	●
Podaxis	*pistillaris*	Desert Puffball			●	●	●	●	●	●	●	●	●	
Polyozellus	*multiplex*	Blue Chanterelle						●	●	●	●	●	●	
Ramaria	*spp.*	Coral						●	●	●	●	●	●	
Rhizopogon	*spp.*	Puffball						●	●	●	●	●	●	
Rozites	*caperata*	Gypsy Mushroom								●	●	●	●	
Russula	*aeruginea*	Tacky Green Russula						●	●	●	●	●	●	
	cyanoxantha	Charcoal Burner						●	●	●	●	●	●	
	delica	Short-Stem *Russula*						●	●	●	●	●	●	

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Russula	*nigricans*	Blackening *Russula*								●	●	●	●	
	vesca	Bare-Toothed *Russula*						●	●	●	●	●	●	
	xerampelina	Shellfish *Russula*	●	●				●	●	●	●	●	●	●
Schizophyllum	*commune*	Split Gill	●	●	●	●	●	●	●	●	●	●	●	●
Sparassis	*crispa*	Cauliflower										●	●	●
Strobilomyces	*floccopus*	Old Man of the Woods						●	●	●	●	●	●	
Stropharia	*rugoso-annulata*	King *Stropharia*			●	●	●	●	●	●	●	●	●	
Suillus	*brevipes*	Short-Stalk Slippery Cap							●	●	●	●	●	
	granulatus	Dotted-Stalk *Suillus*								●	●	●	●	
	pictus	Painted *Suillus*								●	●	●	●	
Terfezia	*bouderi*	Black Kame	●	●	●	●								
	claveryi	Brown Kame	●	●	●	●								
Tremella	*mesenterica*	Witch's Butter	●	●	●	●	●	●	●	●	●	●	●	●
Tricholoma	*equestre*	Man on Horseback	●	●							●	●	●	●
	magnivelare	American Matsutake	●	●				●	●	●	●	●	●	●
Tuber	*aestivum*	Summer Truffle					●	●	●	●				●
	gibbosum	Oregon White Truffle		●	●	●	●	●						
	magnatum	Italian White Truffle									●	●	●	
	melanosporum	French Black Truffle								●	●	●	●	●
	texensis	Texas White Truffle						●	●	●	●	●	●	
Volvariella	*bombycina*	Silky Sheath					●	●	●	●	●	●		

Harvest Calendar

About 1,150 mushroom species in more than 85 countries are considered edible, yet only a small number are considered the most savory. The preceeding calendar shows average time windows when these more popular species are fruiting in North America and Europe.

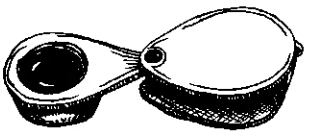
When you find a productive patch, be sure to record its location and the date it was found. Twelve months later, that secret mushroom garden may provide yet another bounty. These discoveries and their subsequent annual flushes are the great rewards for all your initial searching and researching. Join your local mycological society to get a heads-up on the locales and nuances of the species in your region. And consider starting a Radical Mycology group so you can pool knowledge and resources and learn with others.

MycoSchwag

What's a new cool hobby without a bunch of geeky paraphernalia and safety gear? Though mushroom hunting is pretty inexpensive, the following equipment items are worth investing in.

On the Body

- **Bright, right clothes:** Mushroom hunting season often overlaps with the hunting season of animals, so be safe! Multiple layers of non-absorbent clothing and comfortable hiking boots are good options.
- **Compass and whistle:** Getting lost while mushroom hunting is the leading cause of death related to the practice. If you are not familiar with how to use a compass, learn before you leave.
- **Note taking materials:** Waterproof and/or acid-free paper and fade-proof and/or waterproof ink is ideal.
- **10x-30x hand lens:** These low power magnifiers are helpful for observing small identifying features of mushrooms and lichens. They are also great for nerding out on how cool living things look up close.



In a Flat-Bottom Wicker Basket or Drilled-Out Bucket

- **Paper/wax paper bags:** To ensure that edibles don't get mixed with deadibles (a.k.a. toxic species), each collection should be stored in a separate bag. Plastic bags should not be used as they tend to make mushrooms "sweat" and decay rapidly. This is one reason why a basket or drilled bucket is used to carry collections. Baskets/buckets also help the fungi spread their spores as you hike. Bring a variety of bag sizes and more than you think you will need.
- **Knife and small paintbrush:** For harvesting and field dressing mushrooms.
- **Trowel:** For digging up truffles or species with subterranean identifying features.
- **Tackle box:** For protecting and separating delicate species.
- **Dental mirror:** For looking under mushrooms that you don't need to harvest but want to identify.
- **Cereal crop flour:** For making an offering of thanks.

In the Backpack

- **Food and water**
- **Emergency blanket**
- **Waterproof raingear**
- **Flashlight/headlamp**
- **Sunscreen**
- **First aid kit**
- **Tick removal tool**
- **Bear spray**
- **Binoculars:** For determining if that thing over there is a mushroom. Or, hey, what kind of bird is that?
- **Field guides:** Regional tree/plant guides are also helpful for identifying the partners of mycorrhizal fungi.
- **pH and moisture meter:** To determine the parameters of a mushroom's substrate, especially if you wish to grow it later.

In Land, of Land

Crossing the border between forest and field, the senses soften into focus as heightened acuity takes over the mind. The periphery expands, allowing the slightest accents in the forest floor to exaggerate their rare forms glowing among shadow and foliage. Up and down, under and through, the glance is always peering. This is the quiet hunt—a secret in the recesses not considered by others. Weaving, steps are taken cautiously, with precision, and in a meandering simplicity that follows the undercurrents of mycelium woven through the soil, just as a dowser seeks hidden waters.

Soon, the walking meditation becomes familiar—its antiquity felt as forgotten instincts of survival passed down from tribes of gathering ancestors. Demanding nothing, the hunt is to explore, to listen, and integrate in Nature's temples. Singing overheard and rustling below, its webs remind one of the twinned search of mystics and scientists for pattern in the heart of the wild.

The demands of civilization abandoned, the value of the land takes on greater emphasis. Who has lived here? Who lives here now? How have I shaped and defended this land? In wondering, a chance to dialogue with the elders of a place is found. The answers come uniquely, expressed through the lens of each individual's relationship to the land.

To seek the fungi is to travel deeper into Nature's moments in all places and to shape one's life by the rhythms found. Woven in the world, equally built from its cycles of death and rebirth, and intimately tied to its health and protection, fungi teach us to see the mycelium for the hyphae. They see us; they know us. But it is up to each of us to decide how we will come to know them.

Common Conks and Popular Polypores

			Medicinal	Edible
Bjerkandera	*adusta*	Smoky Polypore	•	
Cerrena	*unicolor*	Mossy Maze Polypore	•	
Chondrostereum	*purpureum*	Silver Leaf Fungus	•	
Climacodon	*septentrionale*	Northern Tooth Fungus	•	
Coltricia	*cinnamomea*	Fairy Stool	•	
Cryptoporus	*volvatus*	Veiled Polypore	•	
Daldinia	*concentrica*	Cramp Balls	•	
Daedalea	*quercina*	Thick-Walled Maze Polypore	•	
Daedaleopsis	*confragosa*	Thin-Walled Maze Polypore	•	
Echinodontium	*tinctorium*	Indian Paint Fungus	•	
Fistulina	*hepatica*	Beefsteak Fungus	•	•
Fomes	*fomentarius*	Tinder Conk	•	
Fomitopsis	*cajanderi*	Rosy Conk	•	
	officinalis	Agarikon	•	
	pinicola	Red Belted Conk	•	
Ganoderma	*applanatum*	Artist's Conk	•	
	lucidum	Reishi	•	
	oregonense	Oregon Reishi	•	
	tsugae	Hemlock Reishi	•	
Gloeophyllum	*saepiarium*	Rusty Gilled Polypore	•	
Heterobasidion	*annosum*	Annosum Root Rot	•	
Inonotus	*obliquus*	Chaga	•	
	tomentosus	Wooly Velvet Polypore	•	
Ischnoderma	*resinosum*	Resinous Polypore	•	
Laetiporus	*spp.*	Chicken of the Woods	•	•
Lenzites	*betulina*	Gilled Polypore	•	
Phaeolus	*schweinitzii*	Dyer's Polypore		
Phellinus	*gilvus*	Oak Conk	•	
	igniarius	False Tinder Conk	•	
	linteus	Black Hoof Mushroom	•	
Phlebia	*tremellosa*	Trembling Merulius	•	
Piptoporus	*betulinus*	Birch Polypore	•	
Porodaedalia	*pini*	Pine Conk	•	
Pycnoporellus	*fulgens*	Red Polypore		
Stereum	*spp*	Parchment Fungi	•	
Trametes	*versicolor*	Turkey Tail	•	
	hirsuta	Hairy Turkey Tail	•	
Trichaptum	*biforme*	Violet Tooth Polypore	•	
	abietinum	Violet Tooth Polypore	•	
Tyromyces	*caesius*	Blue Cheese Polypore	•	
	chioneus	White Cheese Polypore	•	
	fragilis	Rusty Cheese Polypore	•	

Legal Issues

The legality of mushroom picking varies by location. In the United States, many state and federal lands require permits or other forms of registration to forage, often with a daily or annual maximum allowed per person. Many state and national parks prohibit mushroom picking entirely. Illegal harvesting can incur fines of $200–500, even for picking one mushroom. If you wish to hunt on private property, be sure to ask for permission from the landowner. Offering to share a part of your harvest is an easy way to gain access to what is likely to otherwise go unclaimed.

- **Chemical reagents:** Not commonly carried. Meltzer's reagent and 3% KOH (discussed later) are the most helpful in the field.
- **GPS tracking device:** For obtaining and recording the exact coordinates of a patch.
- **Topographic map of the area**
- **Photography equipment:** Photos of your hunts aid in identification, increase one's bragging rights, and help recall fond memories of forays gone past. Investing in higher quality photography gear, especially a camera with a macro setting/lens, is suggested for the devout hunter. In low light, use a tripod and long exposure instead of a flash.
- **Cultivation gear:** To help increase species diversity and/or redundancy, consider inoculating logs and stumps with edible, medicinal, or ecologically important species. A small hand drill, palm inoculator, and naturalized plug or sawdust spawn are best for inoculating logs, stumps, and snags. Be sure to only introduce local species/strains and avoid unnatural concentrations of species that could result in an unforeseen long-term ecological disturbance.
- **Spore collection gear:** Pieces of aluminum foil stored in a small metal tin work well for this.
- **Culture collection gear:** A variety of tools can be used to collect cultures of mushrooms in the field. This is especially helpful for cloning mushrooms that are rare and should not be harvested in their entirety. Plastic food storage containers carrying pre-hydrated cardboard can be used to collect cardboard cultures immediately upon harvest. For mushrooms that are high in a tree, hollow pointed arrowheads that have been cleaned with alcohol can be shot with a bow and retrieved to harvest a small tissue sample.

Noting Nuances

Both veteran hunters and burgeoning mycologists rely on the benefits of taking thorough notes during every foray. Noting a mushroom's habitat and fresh appearance in the field is important for ensuring accurate identifications as some characteristics are easy to forget. Features such as coloration and scent can also alter dramatically in just a few minutes after harvesting. Notes ensure that these changes are not overlooked. Likewise, photos cannot capture many identifying characteristics and often cannot be used as the sole means for identifying a mushroom.

Note taking offers the hunter many benefits beyond identifying fungi. Observing and recording information about each collection helps hone one's awareness of the subtleties of each specimen, and to ultimately develop the pattern recognition that underlies quick mushroom identification. Taking good notes also encourages slowing down, looking around, and integrating a bit with the ecological webs that fungi embed within, create, and sustain. Taking the time to note these relationships in all the species that you find—even those you're not planning to harvest—nurtures a relationship with the fungi that is deeper and more intentional than one based solely on a "Can I eat it?" approach. By experiencing and appreciating the complexity of such ecological dynamics, one can shift their foray's emphasis toward the systemic relationships that fungi form and their various effects.

The notes you take in the field can be as detailed as you like. But, at a minimum, recording the following information is recommended to help ease identification later on. The best practice is to number each collection's notes in the sequence of harvest, and place each collection in a unique bag labeled with the same identifying number.

Habitat Information

- **Time and date**
- **Recent and current weather**
- **GPS coordinates**
- **Elevation**
- **Nearby plants**
- **Habitat** (e.g. mixed conifer forest, grassy meadow, road side, etc.)
- **Substrate** (e.g. soil, wood, woody debris, buried debris, leaf litter/duff, other mushrooms, compost, burned soil, or dung)
- **Substrate quality, pH, and moisture content**

Fungus Information

- **General macroscopic features of the fruit body** (e.g. stipe, cap, and hymenium characteristics)
- **Number of specimens**
- **Growth habit** (e.g. solitary, gregarious, scattered, or clustered)
- **Scent**
- **Taste** (That is, the taste when a small piece of the fungus is chewed, held on the tongue for a few seconds, and then spit out and the mouth rinsed with water. Never swallow any amount of an unidentified mushroom.)
- **Coloration and its changes due to drying or handling**
- **Chemical staining** (If you are using chemical reagents in the field.)
- **Presence and characteristics of mycelium and/or rhizomorphs**
- **Unusual traits** (If a mushroom is growing off an uncommon substrate or in unusual conditions, it might be a good candidate for cultivation experiments.)

Approximate Species Count: Cap and Stalk

Agarics	*Agaricus*	200
	Agrocybe	100
	Amanita	600
	Armillaria	45
	Bolbitius	54
	Calocybe	22
	Catathelasma	4
	Chlorophyllum	20
	Chroogomphus	4
	Clitocybe	300
	Clitopilus	102
	Collybia	3
	Conocybe	12
	Coprinellus	42
	Coprinopsis	39
	Coprinus	4
	Cortinarius	2000
	Cystoderma	16
	Entoloma	1000
	Flammulina	10
	Floccularia	4
	Galerina	300
	Gomphidius	13
	Gymnopilus	200
	Gymnopus	300
	Hebeloma	150
	Hygrocybe	150
	Hygrophorus	100
	Hypholoma	44
	Hypsizygus	4
	Inocybe	100
	Laccaria	75
	Lactarius	450
	Lentinellus	24
	Lentinula	8
	Lentinus	40
	Lepiota	400
	Lepista	50
	Leucoagaricus	90
	Leucocoprinus	40
	Leucopaxillus	15
	Lyophyllum	40
	Macrolepiota	40
	Marasmius	500

Approximate Species Count: Cap and Stalk

Agarics	*Melanoleuca*	50
	Mycena	500
	Nolanea	8
	Omphalotus	9
	Panaeolus	98
	Panellus	55
	Paxillus	35
	Phaeocollybia	87
	Pholiota	150
	Phylloporus	50
	Phyllotopsis	5
	Pleurotus	29
	Pluteus	300
	Psathyrella	400
	Psilocybe	138
	Rhodocollybia	30
	Rhodocybe	20
	Russula	750
	Stropharia	32
	Tricholoma	353
	Tricholomopsis	11
	Tubaria	27
	Volvariella	50
Veined	*Cantharellus*	50
	Craterellus	9
	Gomphus	18
	Polyozellus	1
Polypores	*Albatrellus*	27
	Boletopsis	9
	Coltricia	42
	Cotylidia	11
	Polyporus	40
Boletes	*Austroboletus*	27
	Boletus	100
	Lecciunum	75
	Strobilomyces	42
	Suillus	98
	Tyopilus	100
	Xerocomus	20
Toothed	*Hericium*	16
	Hydnellum	39
	Hydnum	120
	Pseudohydnum	1
	Sarcodon	49

Species Lists

In some instances, avid hunters also take less rigorous notes of the species and genera that they can identify on sight, as when on a casual hike. For each outing, a list is titled with the date, location, and any other pertinent information about the site. Below this information, the species names are listed as they are encountered. For mushrooms that are only recognizable to genus, the abbreviation "sp" can be used, with additional "p"s added to track the number of unidentified species in a genus. For example, *Russula sp* = one *Russula* species, *Russula spp* = two *Russula* species. *Russula sppppp* would indicate that five unidentified *Russula* species were seen. Along with simply tracking the diversity of fungi one encounters throughout their life, these lists also help build familiarity with the fruiting cycles and fungal demographics for a given site, as well as the seasonal and geographical range of a given species.

Identifying Plants

To increase the quality of notes and enhance general familiarity with fungal habitats, many hunters also learn to identify local fungi-associated plants, such as trees, orchids, and plants in the Ericaceae that form mycorrhizal relationships. Most trees can be identified solely by the shape, size, and arrangement of their leaves. The bark pattern and overall shape of a tree is also a helpful identifier for many species.

Grinnell Journaling

If thoroughly documented and preserved, field notes can serve as a long-term record of a local ecosystem, and be used as educational tools for future naturalists and mycologists tracking the transformation of a place over time. As the world becomes ever more urbanized and the biological sciences increasingly focus on the genetics of life instead of their field observation, the art of the naturalist fades into obscurity. Today, 90% of the average American's life is spent indoors.[3] How will losing connection to the features and creatures of a culture's land base affect future generations? If the adults of tomorrow are unable to identify wild berries to pick in the summer, how will they know which endangered plants to defend, let alone develop a reason for why defending a plant is important to begin with? The world needs more naturalists, ecologists, biologists, botanists, and mycologists with field experience and the desire to share their knowledge with future generations. The act of documenting one's experience in the wild is a simple means to help retain a cultural memory of an environment as the world moves into an increasingly technological tomorrow.

One of the most respected and refined formats for creating thorough field recordings was developed around the turn of the 20th century by the zoologist Joseph Grinnell. An ecologist ahead of his time, Grinnell recognized the long-term need to document how species diversity and distribution patterns change over decades and centuries. To this end, Grinnell devised a method of nature journaling that would create a written snapshot of an environment through the transcription of field notes into a flowing essay that is well-organized. Most practitioners of the Grinnell system still adhere to its original four-part protocol.

The Field Notebook

Similar to the pocket notebooks used for note taking on casual forays, Grinnel Field Notebooks track shorthand information about every collection. However, rather than just noting information about the fungus being observed, greater attention is paid to details of the environment, especially in regard to the other visible flora and fauna. Other additional information that is often recorded includes the route taken to the location, arrival and departure times, and notes on the blooming and pollination patterns witnessed. Once a Field Notebook is filled up, it is kept for reference.

The Field Journal

Once back from the field, the detailed notes from the Field Notebook are translated into a separate journal as a short essay. Beyond noting what was witnessed, journal entries also include explanations of how travel occurred, how the fungi were generally hunted, and other miscellaneous acts. To make it easy to quickly find important information, the scientific names of species and any other essential details are underlined. One side of each piece of paper is written on, while the other side is used for drawing maps or sketches of the environment, or for attaching papers. Most importantly, journal entries should be made within 24 hours as details of an excursion tend to fade quickly. A Field Journal is used for one calendar year. At the beginning of each year, the old journal is numbered, stored, and then replaced with a new one. *"No Journal This Day, No Sleep This Night!"*

The Species Accounts

The Species Account section of a journal records every instance that a given species is encountered in a year. Each Species Account is titled with the name of the species and is filled with dated, short, first person essays of each encounter. Things to note include the phenology (natural cycles in occurrence, such as climate and season), ecology, morphology, and distribution of the species. Species Accounts help one learn the various habits of a species over time and across a range of habitats. This information can be written in a separate section of the Field Journal or in a separate journal.

The Catalog

The Catalog is used to track all of one's collections. It assigns a number (starting with 1) to every specimen that is picked up during field observations. Personal coding systems can be devised to help track when and where a collection was made. The Catalog can be in a separate section of your Field Journal or in a separate book. Each page is titled "Catalog." Catalog collections tend to correspond to numbered objects preserved in a personal or institutional herbaria, which are either placed in a labeled container or tagged with corresponding information.

Harvest, Ritual

The act of harvesting, though a quick and forgetful moment for some, can be viewed with a sense of solemnity. Each collection is a small piece of the world's bounty. Each cut, the culling of one life that provides extension for another. As such, some choose to honor the fungi by performing symbolic acts to give thanks for the life being received. Acts such as asking the fungi for permission to harvest, verbally or mentally conveying intentions of how the fungus will later be worked with, or leaving a physical token are a few means for developing a more intentional connection with the fungal realm. Pliny the Elder suggested leaving some flour of cereal crops as an offering of thanks to the fungi. Such harvest rituals provide a means to express feelings in a way that a purely (eco) logically guided approach to hunting never could, ultimately providing each individual with the means to enhance their personal relationship with the Queendom.

Approximate Species Count: Non-Cap and Stalk

Brackets & Conks	*Bjerkandera*	2
	Bondarzewia	5
	Cerrena	8
	Chondrostereum	1
	Climacodon	6
	Cryptoporus	2
	Daedalea	17
	Daedaleopsis	6
	Daldinia	28
	Echinodontium	5
	Fistulina	8
	Fomes	12
	Fomitopsis	40
	Ganoderma	26
	Gloeophyllum	9
	Grifola	9
	Inonotus	86
	Ishnoderma	10
	Laetiporus	13
	Lenzites	6
	Phaeolus	3
	Phellinus	154
	Phellodon	21
	Piptoporus	4
	Porodaedalia	9
	Pycnoporellus	2
	Pycnoporus	5
	Sprassis	6
	Trametes	5
	Trichaptum	20
	Tyromyces	30
Stalkless Agarics	*Crepidotus*	53
	Pleurocybella	2
	Schizophyllum	6
Jelly Fungi	*Ascocoryne*	5
	Auricularia	28
	Calocera	15
	Dacrymyces	39
	Dacryopinax	15
	Exidia	20
	Guepinopsis	7
	Phlogiotis	1
	Tremella	100

Approximate Species Count: Non-Cap and Stalk

Crusts or Resupinate Fungi	*Coniophora*	20
	Heterobasidion	16
	Irpex	49
	Merulius	2
	Phanerochaete	56
	Phlebia	50
	Poria	6
	Serpula	29
	Stereum	27
Puffballs & Earthstars	*Bovista*	103
	Calbovista	2
	Calvatia	63
	Geastrum	73
	Lycoperdon	50
	Pisolithus	16
	Podaxis	50
	Rhizopogon	150
	Scleroderma	25
	Vascellum	17
Cup Fungi	*Aleuria*	40
	Paxina	4
	Peziza	100
Stinkhorns	*Aseroe*	4
	Clathrus	22
	Ileodictyon	2
	Lysurus	6
	Mutinus	12
	Phallus	18
	Pseudocolus	3
Bird's Nest Fungi	*Crucibulum*	3
	Cyathus	45
	Mycocalia	6
	Nidula	6
	Nidularia	2
Corals & Clubs	*Clavaria*	175
	Clavariadelphus	22
	Clavulina	45
	Cordyceps	400
	Geoglossum	28
	Ramaria	200
	Thelephora	50
	Tremellodendron	8
	Trichoglossum	19
	Xylaria	200

The Take

To ensure that your hunts have the least amount of impact, mushrooms should be harvested in a manner that both minimizes soil disturbance and encourages sporulation. Soil compaction is one of the greatest threats to mushroom populations as it has been directly linked to declines in the distribution of several mushroom species in Europe. If you are hunting with a small group of people, try to walk in a single file line. Conversely, if you are with many other hunters, spread out to reduce trampling. When walking on steep slopes, follow deer trails where possible or descend diagonally to reduce erosion.

The approach to collecting varies depending on the intention of use. If you are not sure of the identity of the species you are harvesting, try to collect several specimens at various stages of growth. Many species have notable morphological changes (e.g. gill color, veil shedding, and cap features) that occur in age. Regardless of age or population of the species, be sure to collect the entire mushroom, including any underground features such as a volva, subterranean stem, or rhizomorphs.

When harvesting mushrooms for consumption, it is best to field dress each fungus at the time of harvest. For mushrooms, cut or scrape off the dirty stem bottoms and clean off the dirt with a small brush, your breath, and/or your hands. If a species is known to have bitter gills, pores, or teeth, cut these off in the field and put them in a place where their spores might grow, so as to facilitate a semi-natural inoculation.

An ethical wildcrafting approach to harvesting is to only collect fungi that have dropped some spores and to leave at least 25% of what you find for the next person (human or otherwise). If you are harvesting a thin fleshed or tough mushroom that you wish to later culture, also try collecting a small piece of its myceliated substrate in case the fruit body proves challenging to clone. Place each collection in a separate bag inside your basket or, if it is to be cultivated, roll it into moist cardboard and place it in a sealed container.

The Basics of Field Guides and Keys

Once you have found some fungi and gotten them safely back to your tent, van, home, or lab, the time has come to identify them. For mushrooms, the first step is to determine the species' general form or "stature type." Some species form belowground, or *hypogeous*, fruit bodies. These include the truffles and their look-alikes. Most of the known macro fungi, however, produce aboveground, or *epigeous*, mushrooms.

Non-Cap and Stalk

In general, the more commonly encountered mushrooms that do not have a stereotypical "cap and stalk" form tend to be relatively easier to identify to genus than the cap and stalk mushrooms. Many "non-cap and stalk" mushrooms tend to get overlooked by most beginners due to the fact that many are inedible or, at the least, not as "choice" as the more popular species. However, this does not imply that these fungi have little value for humans or other people. Many species in this group play critical ecological roles, have very long or unusual lifestyles worthy of appreciation, and/or are highly medicinal. Non-cap and stalked mushrooms tend to fall into the following broad groups:

- **Polypores and Brackets:** Woody, leathery, or fleshy fruit bodies. Often shelf-like or hoof-shaped. If a stalk is present, it is generally off-center. Often found growing off of wood, but may be on the ground. Spores are produced in round or maze-like tubes that are not easy to remove.
- **Stalkless Agarics:** Shelf-like, fleshy fruit bodies. Spores produced on delicate gills. Typically found on wood.
- **Jelly:** Gelatinous or rubbery blobs of various shapes. Generally found on wood, though some species are terrestrial.
- **Crusts:** Crust-like and not gelatinous. Often on wood.
- **Puffballs and Earthstars:** Round to pear-shaped fruit bodies. Interior filled

with a powdery spore mass at maturity.

- **Stinkhorns:** Phallic, net-, or basket-shaped fruit bodies that arise from an egg or vulva. Often containing or coated in a stinky spore slime.
- **Bird's Nest:** Tiny cup-like forms filled with egg-shaped spore pods.
- **Corals and Clubs:** A mixed bag of ground-dwelling, club-shaped, and/or branching fungal forms.
- **Cup fungi, Morels, and look-alikes:** Ascomycetes that come in a variety of brain-like, lobed, cupped, or saddle-shaped forms.
- **Truffles and look-alikes:** Lumpy, ball-, or blob-shaped. Fruiting underground or rising to the soil surface at maturity. Spores produced internally and spread by animals.

Approximate Species Count: Non-Cap and Stalk

Morels & Allies	*Gyromitra*	18
	Helvella	35
	Morchella	50
	Verpa	5
Truffles & Look-alikes	*Leucangium*	2
	Melanogaster	25
	Terfezia	37
	Tirmania	7
	Tuber	86

Cap and Stalk Mushrooms

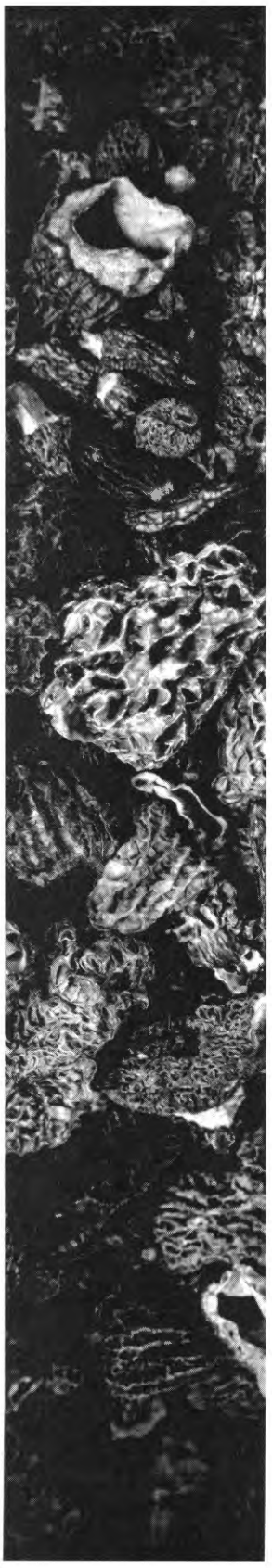
Compared to the above group, learning to identify a "cap and stalk" mushroom to species can be a bit more daunting for the beginner due to the large number of species in this category. Further, the gilled cap and stalk mushroom category (the agarics) is perhaps the most overwhelming group of all the Basidiomycete mushrooms due to its large number of genera. Some agaric genera are also so large that it can be quite challenging to identify a mushroom in that genus to species. Good examples of this challenge are with the genera *Russula* (ca. 700 species) and *Cortinarius* (ca. 2000+ species). However, as the cap and stalk mushrooms contain many of the more commonly eaten fungi, this group is where most people begin to hone their identification skills.

- **Agarics:** Cap with gills. A central stalk may or may not be present. Spore print can be easily obtained.
- **Veined:** Similar to agarics but with blunt ridges/veins instead of well-defined gills.
- **Boletes:** Cap with tubes or pores on the underside that are often easy to remove. A central stalk is usually present. Fruiting body is fleshy and not tough. Spore print can be easily obtained.
- **Toothed:** Spores produced on tooth-like structures.

Once you have determined a mushroom's stature type, one of the first steps toward identifying its genus may be to take a spore print. This is especially true for the agarics, as the spore color of these fungi can quickly help narrow down the potential options for a given mushroom's genus. To take a spore print, place a piece of the mushroom's spore bearing structure (typically located on the underside of a cap) facing downward on top of a piece of paper. Most mushrooms have colored spores, making white paper a good choice. A heavy deposit of white spores is often visible even on white paper. However, to more easily view the lighter and whiter spores of some species, black paper can be used. If you do not have an idea of what the spore color is, use a microscope slide, which can be placed over white or black paper and/or used for microscopic viewing of the spores. Aluminum foil is another good option, as the neutral color allows for color analysis, and because it is an excellent spore storage material. Cover the mushroom with a bowl to reduce drafts and allow it to sit undisturbed for 4–24 hours. After that time, remove the bowl and mushroom piece to reveal the color of the spore deposit.

In general, patience and practice are central to developing a greater ease in identifying mushrooms. Seasoned hunters are often able to quickly name the genus or even the species of a mushroom using pattern recognition (though this may be a reflexive, unconscious process). For the agarics, a good trick for identifying genera is to learn the defining combination of gill attachment, spore color, habitat, silhouette form, and veil characteristics for each genus. Flash cards are quite helpful in this process.

Once you have determined the genus of the mushroom at hand, the next step is to narrow in on the exact species you are working with. How to go about this depends on the identification resource you are using. Some guides are not very well arranged and are more like a collage of descriptions and photos, requiring you to check the descriptions of each species in the genus. Well-organized

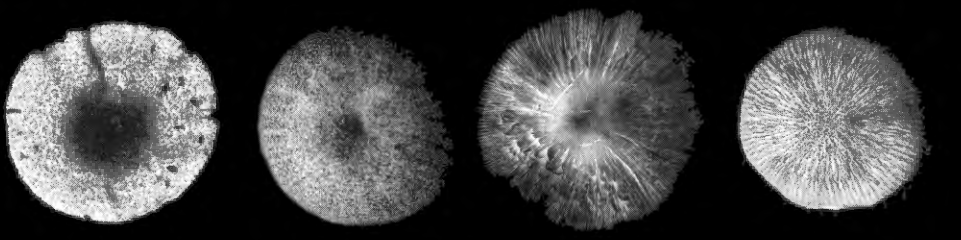


guides offer dichotomous keys that walk you through a serious of yes/no type questions to ultimately determine the proper species. If you do not have a field guide handy, the keys to many genera are free online. The Pacific Northwest Key Council offers free online mushroom identification tools.[4]

Regardless of your identification resource, it is recommended to compare descriptions between several resources to be absolutely positive of your identification. The descriptions offered in guides can vary based on the attention to detail given by an author. The best guides include macroscopic as well as microscopic features. If you are not positive of an identification, do not consume the fungus!

LBMs

If you are just learning to hunt, avoid trying to identify the ubiquitous Little Brown Mushrooms (LBMs) that populate the many nooks, crannies, log bottoms, fields, and ditches along your hikes. While it is definitely exciting to pick such beautiful lil' mushrooms and enjoy their form, it is much less exciting to sit in front of a field guide for hours trying to determine which of the thousands of tiny little mushrooms they are—an often impossible task without the aid of a microscope. Most field guides don't even describe these mushies as they are generally not held in high regard due to their toxicity or poor flavor (although all mushrooms provide important ecological roles). Many of these classic challengers are found in the genera *Collybia, Cortinarius, Galerina, Inocybe, Marasmius, Mycena, Psathyrella,* and *Pholiota.*



Macro Mushroomery

Once you have narrowed down your candidate species, the next step is to confirm that every feature in the species description in your field guide(s) matches your collection. For many mushrooms, this can be done by viewing the fungus' macroscopic features. Typically, these include the following:

- **Cap:** Diameter, shape, side and top view, color changes due to age, bruising or drying, universal veil remnants, margin features, taste, odor, or other surface features.
- **Veil(s):** Presence or absence, evanescence or persistence, texture (membranous, fibrillose, glutinous, or granular), shape, color, and location and pattern of remnants.
- **Gills:** Attachment to stalk, spacing, thickness, appearance, forking, color and color changes, and the appearance and characteristics of latex (milk).
- **Stipe:** Attachment to cap, length and diameter, shape, quality of interior, color and color changes, surface features, taste, and odor.

For some trickier species, a drop or two of a chemical reagent may need to be placed on the mushroom's tissue to see if an identifying color change occurs. Meltzer's reagent is commonly used for this purpose. With Meltzer's, a color change to blue-black is called *amyloid*, a red-brown color change is *dextrinoid*, and a lack of color change is *inamyloid.* All *Russula* and *Lactarius* as well as some *Amanita* species have amyloid spores. *Lepiota* species have dextrinoid spores. To make Meltzer's reagent, dissolve 20 grams chloral hydrate, 0.5 grams iodine, and 1.5 grams potassium iodide in 20 milliliters of warm water. Three to five percent potassium hydroxide (3–5% KOH) is another common reagent. Other reagents are used as well, but are generally for more obscure species.[6]

Mycroscopy

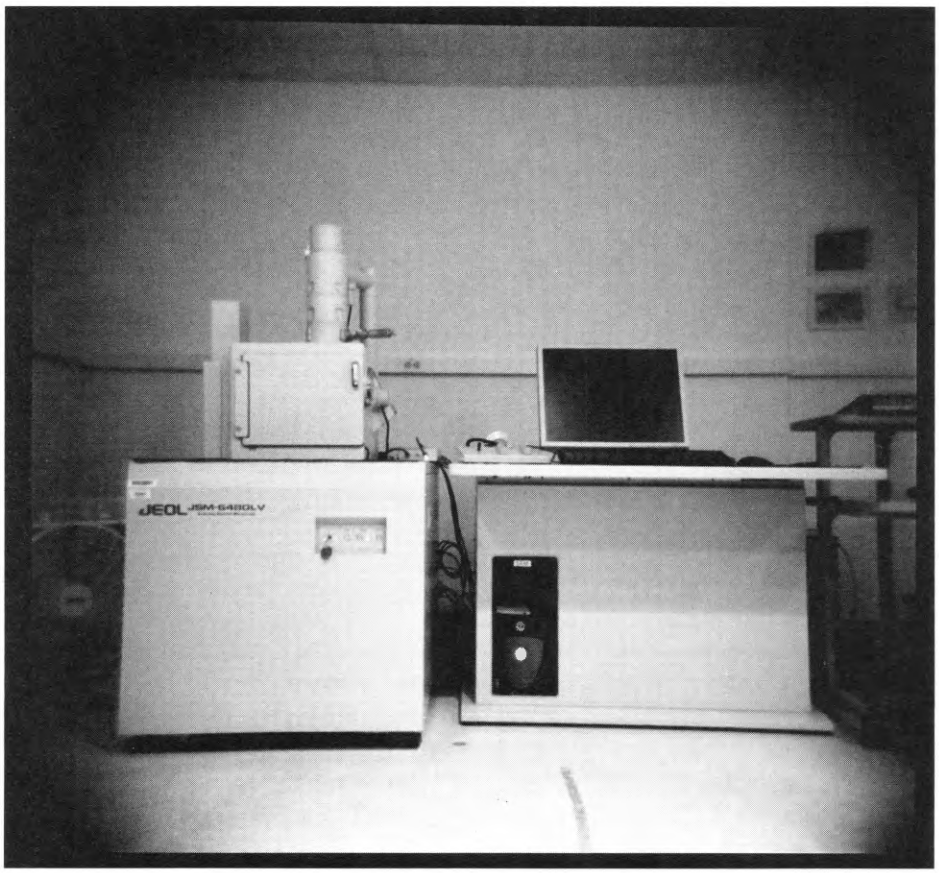
When a mushroom's readily visible features aren't enough to confirm its identity, checking the fungus' microscopic features is often the last step to finishing the name game. This is especially true for certain genera such as *Conocybe* and *Galerina*, which contain many species with nearly identical macro features. Even if you don't need to check the micro features of a fungus to confirm its identity, peering into the tiny world of fungal forms can be pretty bizarre and engaging in its own way. To begin, you will need to get the right kind of microscope to match your needs.

Dissecting/Stereo Microscopes

Relatively inexpensive and low powered, these scopes are meant for close observation of macroscopic features. They are quite helpful for identifying lichens and wowing out on mushrooms in general, but they aren't going to get close enough to measure spores or view other minute features.

Scanning Electron Microscopes (SEMs)

Unlike light microscopes, which use photons to produce an image, SEMs spray a field of electrons at an object and translate the time it takes for those electrons to hit the object and bounce back into a three-dimensional rendering. To ensure that the reading is accurate, the sample must be completely dried and sputter coated with an ultra thin layer of metal. As such, SEMs are not commonly used for identification purposes. However, SEMs are ideal for research projects as they are able to reach incredible magnification levels of up to 500,000x. SEMs can cost upwards of $250,000. So if you are able to access one through a local university or other institution, be sure to take advantage of such a rare opportunity. Alternately, check out the work of DIY engineer Ben Krasnow, who has built a simple SEM for $1,500.[7]



An SEM at a public college in Washington state. The small stage for the microscope is behind the door on the upper portion of the machine.

The Language of Descriptions

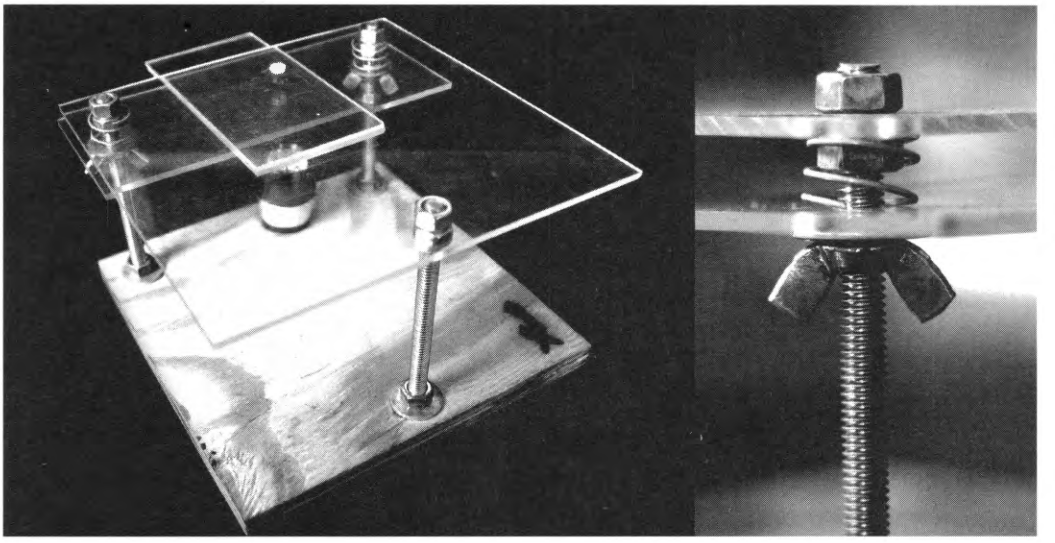
A challenging but unavoidable aspect of identifying mushrooms is the need to learn an array of unique adjectives used by mycologists to describe the subtle features of fungi. While some field guides offer descriptions that are easy for a beginner to understand, many books are rather technical in their details. This can be a bit off-putting at first, but in time such terms quickly become an integrated aspect of one's note taking and research practice. As it currently stands, this language barrier is one of the unavoidable hurdles to accessing mycology that simply must be overcome by any Radical Mycologist wishing to gain a complete understanding of the fungi in all their forms.

Compound Microscopes

These multi-lens scopes are those most commonly used by mycologists. For information on properly preparing, calibrating, using, and storing a compound microscope—as well as basically everything you need to know about microscopic mushroom features—refer to the book *How To Identify Mushrooms To Genus III* by David Largent. Nicer compound scopes achieve at least 1,000x magnification and cost several hundred dollars. A nice, simple model is the Amscope B-100ms. The more expensive the scope, the better the image quality it achieves.

The Ten Dollar Microscope

This simple yet incredibly effective design was developed by Kenji Yoshino to turn any smart phone into a microscope.[8] At its core, this DIY microscope relies on the refraction of lenses taken from laser pointers to magnify the image in a smart phone camera. Similarly, many people have good results simply lining up a hand lens with the lens on a smart phone.



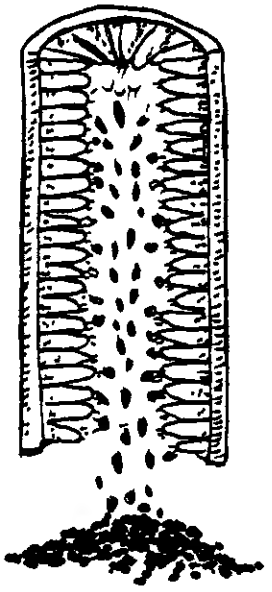
The $10 Microscope is comprised of two lenses, a stage, wingnuts, plexiglass slides, compression springs, and a little LED light.

Spore Stature

Once you've obtained or made a microscope, the next step is to observe and measure the mushroom's spores. The eyepiece of most compound scopes have marker lines that need to first be calibrated with a stage micrometer to determine their length at each magnification. If these lines aren't calibrated, you won't know how to determine the relative length of these marker lines and thus will be unable to accurately measure spores or other features. To load spores, scrape some off of a spore print onto a slide. If the spores are dry, they should be rehydrated with 70% isopropyl or 5-10% KOH to ensure proper measurements. Before loading the slide under the scope, add a drop of water to the slide and drop a slide cover slip down to cover the spores, trying to avoid air bubbles.

The length, width, and shape of spores are some of the primary features observed. The standard practice is to measure the size of 30 spores and then determine their average. This is tedious. A faster method for achieving this goal is to take a digital photo of the spores through the microscope's eyepiece (a variety of adapters and USB eyepieces exist for compound scopes) and then use the open source programs Piximetre or ImageJ[9] to quickly measure the spores. The spores of some species also have projections, netting, or other types of ornamentation that are used for identification.

Squash Mounts



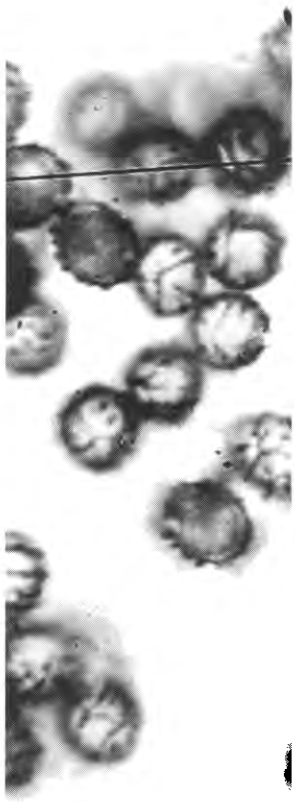
Other microscopic features require taking a thin cross-section from somewhere on the mushroom body. The most common sections are taken as a top down view (cross-section) of the gills, as a vertical slice (longitudinal section) of the cap, or as a transverse section of the stipe walls. Using a new razor blade, take as thin of a cut as possible of these areas. This is often easier with dry specimens and when looking under a compound microscope. Once the slice is obtained, place it on a slide, add a drop of water, and let a cover slip fall sideways over the sample. If the tissue is hard to see, chemical stains can be used to aid in visualization. The stain Congo Red A (1%) is often used to stain hyphal walls and Phloxine A (1%) is helpful for dyeing the interior of hyphae. Diluted food coloring can work too. Microscopic features of the cap that are typically observed in Basidiomycetes include:

- **Basidia:** Shape, dimensions, number of spores per, and any chemical reactions.
- **Cystidia:** Location, shape, dimensions, pigmentation, ornamentation, contents, and any chemical reactions.
- **Gill trama:** Types of hyphae present and their dimensions, pigmentation, contents, and overall arrangement.

Sometimes, these features are also checked to confirm an identification:

- **Cap cuticle:** Number of layers, morphology, chemical reactions, presence of cystidia, or other features.
- **Flesh of cap or stipe:** Types of hyphae present, pigmentation, chemical reactions, and the presence and features of cystidia.
- **Veils:** Hyphal/cell types, pigmentation, and any chemical reactions.

Other microscopic features include clamp connections and the presence and coloration of septa between cells. Ascomycete fungi bear a range of their own unique microscopic features. These include the shape, size, and branching patterns of asci, paraphyses, conidia, ascospores, and conidiospores. Good field guides and keys will detail these nuances per species.



The Taste for Truffles

Though often missing from most mycological forays, the hunt for subterranean truffles is not unlike the search of mushrooms: the seeker must go to the optimal habitat of the target species at the right time of year and observe. With a little bit of luck and a lot of persistence, the reward can be some tasty ground scores and their annual harvest each year after.

There are about 200 edible truffle species in the world, all of which are Ascomycetes. There are many other truffle-like fungi; not all are Ascomycetes. In Europe and North America, the most popular truffle genus is *Tuber*. These truffles are generally only found near the base of species-specific trees, just a few inches below the forest floor where the soil and litter meet. All trees in the pine, oak, birch, and willow families associate with truffle-forming fungi. Truffles rarely form associations with *Thuja*, juniper, ash, maple, or fruit trees. Ideal sites are those with sparse ground cover near logs and with loose or compacted soil. However, other areas are worth checking as well.

Animals are some of the best teachers in the truffle hunt. The small holes or impressions left by mycophagous voles and other mammals at the base of a candidate tree are often a telltale sign that underground fungi are present. But, although a passing animal has dug a bit, don't assume that the truffle is gone for the critter might have only taken a bite. If you get low enough, a cloud of yellow truffle flies hovering above the ground is also a good indication that the hunt is well underway.

Larger animals with a strong nose can assist as well. Traditionally sow pigs were used to help find truffles, as one of the compounds produced by these fungi is 5 alpha-androst-16-en-3alpha-ol, the main sex pheromone of male pigs and a quick means for eliciting a physical reaction in a

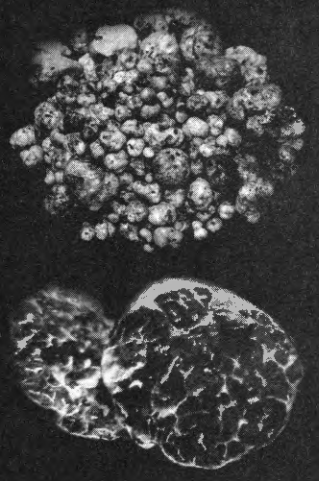
sow. Italian trufflers find the best sow hunters in a pig litter by simply walking into a group of piglets with a truffle in their hand and selecting the squealer that shows the most interest. In recent decades, dogs have become a more popular companion to help in the hunt. Dogs can not only be trained to detect the scent of truffles but they also are easier to control than a large sow.

Training truffle dogs is done in the summer by hiding a strong smelling truffle in a sewn leather pouch in a room. When the truffle is found, the dog should be made to sit and then offered a reward. Once the dog can do this without harming the truffle, the pouch is then buried outdoors and the process repeated until the dog is ready to be taken to an area where truffles are known to fruit. Poodles and Lagotto Romagnolos are two dog breeds that are generally preferred for truffle hunting.

Once you have found some truffles, be sure to take care when you harvest them so as not to disturb the soil too much. Some hunters use a trowel, small hoe, or rake to remove debris and uncover the truffles. Most truffle species are rather hard to distinguish from one another. But, as luck would have it, the most prized edibles are quite easy to identify by cutting them in half and observing their interior. This cutting also ensures that you have not harvested an immature *Amanita* button, which would have the outline of an immature mushroom inside. Based on animal studies, no truffle is known to be poisonous. And based on many taste tests, the following three species are considered the most delicious in North America.

Oregon Fall White (*Tuber oregonense*)
Knobby and potato-like. Opaque whitish to yellowish or olivaceous peridium that turns to a reddish-orange-cinnamon color. Gleba is initially white, but in age turns brick-red to brownish with white marbling. Cracking with age. Emitting a complex savory scent reminiscent of cheese, garlic, and spice. Grows in association with Douglas-fir trees that are 8–65 years old. Found from California to British Columbia. Said to be on par with the more famous Italian White (*Tuber magnatum*). Occurs fall–late winter.

Oregon Spring White (*Tuber gibbosum*)
Nearly the same description as *T. oregnonense*, but with a near translucent peridium and less reddening in age. Occurs late winter–spring.



What if I Can't Identify it?

If you are unable to identify a fungus with the tools at hand, several options for refining your ID are as follows:

- Run through the keys again. It's easy to make a mistake and end with the wrong candidate.
- Cross-reference the species' description with as many other books as possible.
- If you think you know the family or genus of the sample, check online for the most current key.
- Take it to your local mycological society.
- Post photos and your collection notes on www.mushroomobserver.org. This free online community of amateur and professional mycologists is intended to ensure the accurate identification of fungal species around the globe.
- Preserve the specimen using the techniques below and send it along with your collection notes and a spore print to an expert in the suspected genus. If it is an unnamed species, you may have a chance at naming it!

Oregon Black (*Leucangium carthusianum*)
Black-brown exterior enclosing a gray–olive–brownish gleba. Has a distinctive "salt and pepper" interior. Often found beneath Douglas-firs along the west coast but can be found in urban areas. Smells fruity when mature.

In desert environments, truffles in the genera *Terfezia* and *Tirmania* are among the most coveted edible and medicinal fungi. However, hunting desert truffles calls for slightly different tactics than woodland truffles. In the Kalahari, locals look for areas where mongoose and bat-eared fox have been digging, often near the camel thorn plant (*Acacia erioloba*) or plants in the genera *Cistus* and *Helianthemum*. Of the estimated 5,000 truffle and truffle-like species in the world, about 1,500 exist in Australia.[5] In France and Spain, *Terfezia* species are often found in association with plants in the rock rose family (Cistaceae). These truffles can also create a hump in the desert that casts a distinct shadow. If the ground is cracked from high heat, hunters often return after a rainfall to ensure that a greater yield is obtained. Harvests are generally made between February and April.

Identifying Endophytes

Endophytic fungi can be rather easily observed within plant matter (especially leaves) using a light microscope or, with the aid of a fluorescent dye, under a microscope equipped with fluorescence optics. Identifying these fungi, however, is a bit more challenging. As discussed in Chapter 9, the mycelium of many endophytic fungi can be cultured on agar plates rather easily, but most cannot be identified from their mycelium alone. If the fungus forms conidia, identification to genus or species may be possible; if it doesn't, genetic analysis will likely be required for identification. However, genetic identification may not be 100% positive, due to the currently limited scope of understanding surrounding endophytic fungi.

Identifying Slime Molds (Mycetozoa)

While not true fungi, slime molds can be studied using many of the same tools and techniques covered in *Radical Mycology*. The Myxomycetes and Dictyostelids tend to live as single-celled organisms in damp areas, and will occasionally congregate when food supplies are limited to form macroscopic spore-bearing structures. Once in these congregated forms, the clusters can often be identified by their general appearance alone. These slime molds are covered in a number of dedicated field guides.[14]

On the other hand, the micro slime molds—the Protostelids—are so small that their identification requires the application of some of the agar-based culturing skills covered in Chapter 8. In

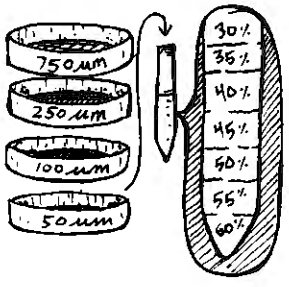
general, Protostelids can be coaxed from plant debris that has been harvested in the field, soaked in sterile water for several minutes, and then placed into a petri dish filled with (low nutrient) wMY agar. Within a few days, the slime molds tend to grow off of the plated plant material, at which point the Protostelids can be more easily viewed under a compound microscope. The Eumycetozoan Project at the University of Arkansas is one of the few research centers in the world studying slime molds. For more information on this project, including free resources for identifying slime molds, be sure to visit their website.[15]

Identifying Arbuscular Mycorrhizae

Determining the presence and diversity of arbuscular mycorrhizal fungi (AM) can provide a variety of insights into the health and regenerative state of an ecosystem. For example, certain genera of AM are indicators of heavily tilled or polluted lands. Likewise, a diverse AM population can indicate that a habitat has not been disturbed in several years. However, as AM do not produce macroscopic fruiting bodies, their identification requires a unique set of tools and practices for isolating and observing their spores and mycorrhizal structures.

The first step in this process is to collect soil cores from a vegetated area to a depth of at least 12 inches (30.5 cm). This depth ensures that the various fungal species living at different soil horizons are accounted for. If possible, collect the soil several weeks after the local vegetation has gone into hibernation for the winter or, alternately, after watering has been intentionally halted in the height of summer. This will help ensure a heavy spore set by the fungus. Once harvested, the soil is run through a series of metal sieves to filter out rocks, root fragments, and other large particles. Scientific metal sieves sized 500 µm, 53 µm, and 38 µm are stacked and the soil is washed through the sieves using water. After washing, the bottom sieve will contain the AM spores along with a mixture of clay minerals.

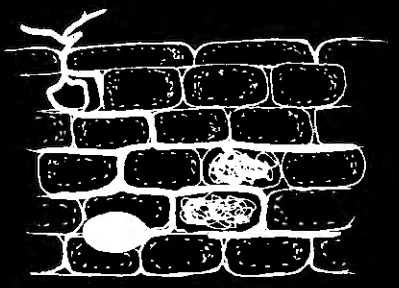
To separate out the spores, this clay/spore mixture is then placed into a test tube filled with layers of sugar water of increasing densities. Higher density sugar water is placed at the bottom and successive layers are added on top to create a "sucrose gradient." The bottom layer is 60% sucrose (60 grams sugar, 40 milliliters water), and each subsequent layer decreases in concentration in increments of 5% until a top layer of 20% sucrose is created. Once the gradient is created, the spore/clay mix is carefully added so as not to mix up the sucrose layers, and the mixture is centrifuged for two to three minutes. After centrifuging, the dense clay particles will have settled to the bottom of the test tube and the spores will remain suspended in the middle of the tube. These spores can then be removed from this middle layer with a pipette or syringe, and further washed on the 38 µm sieve or directly plated on a slide for identification under a dissecting scope. To ensure that you are looking at an AM spore and not another organism, look for a liquid droplet inside the spore and a short protruding stalk. AM spores are identified based on their morphology, generally to genus. As noted in Chapter 1, identifying AM fungi to species is very challenging. Identifying characteristics typically include the arrangement, shape, size, color, ornamentation, wall width, staining reactions, contents, and developmental stages of the spores.



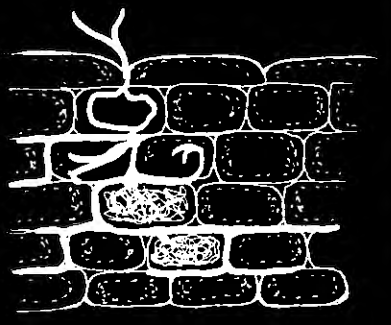
If the spore has germinated, hyphal structures produced in the soil and root tissue can also be used to aid in identification. To observe and identify root structures, you will first need to clean and stain the roots. Ideal root samples are taken from finer, more fibrous root tips. Select one to two grams of material and clean it for a few minutes in 10% KOH, and then autoclave the sample at 15 psi for 15–20 minutes to "clear" the tissue. The cleared roots should then be stained. A simple and safe way to do this is to place the freshly autoclaved root fragments in a mixture of 5 milliliters of ink and 95 milliliters of household vinegar. After three minutes in the solution, the roots are then washed in tap water that has had a few drops of vinegar added to it. Suggested inks include red from Parker, Blue from Pelikan, and black from most companies. Alternately, mycorrhizal structures (dead or alive) can be viewed within and outside of roots by being excited under the blue and/or green light of an epifluorescence microscope. For extensive information on harvesting and identifying AM fungi, visit the website for the International Culture Collection of Arbuscular Mycorrhizal Fungi at West Virginia University.[16]

Common AM Genera

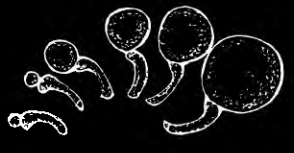
Glomus *(top)*
Glomus species are easy to recognize by their growth patterns inside of roots, with inner root hyphae producing relatively straight lines along the root cortex, H-shaped branching patterns, and oval-shaped vesicles between cells. The mycelium generally has thickened or multilayered walls that produce dark staining. Spores form centrally at the end of the hyphal tip



Acoulospora *(center)*
Hyphae in the outer root cortex is generally more looped and irregularly branched than *Glomus* species. Inner hyphae are thin-walled and do not produce a dark stain. Rectangular to lobe-shaped vesicles with thin walls are also characteristic.



Scutellospora *(bottom)*
Hyphae produce loops near the point of entry into the root. Branching in roots is similar to *Acoulospora* but with thicker, darker staining walls. No internal vesicles. Wispy arbuscules and a thick arbuscule trunk are commonly seen. Spores form non-centrally from the hyphal tip.



Gigaspora
Similar root myceliation to *Scutellospora*, but with thicker hyphae. Spores form non-centrally from the hyphal tip.

Fungi for a Future

If a fungus is left to the winds of consumption or decay, its legacy can only extend to those few animals and microbes that are afforded the luck to view its beauty or dine on its flesh. However, if the experience of a mushroom sighting is preserved and shared, its impact on society can extend from the few to the many and thereby provide a record of the fungus' character and, along with it, a slightly deeper insight into the whims of each special species.

By preserving fungal collections, one is also preserving a degree of reverence for Nature in general. The act of preserving a collection is an act of framing each intersection between human and fungus as a small step toward a greater cultural and global understanding of the world's ecologies. Thus, any preserved collection can serve to help shift dialogues that define the fungi by their degree of edibility or "use" into opportunities for raising awareness around the beauty and significance of

Approximate Wild Mushroom Market Values

Species	USD/kg
Boletus edulis	10–30
Cantharellus cibarius	5–35
Cantharellus tubaeformis	8–25
Craterellus cornucopoides	20–30
Hydnum repandum	10–25
Morchella spp.	50–200
Tricholoma magnivelare	16–200
Tuber gibbosum	200–300
Tuber magnatum	6,000
Tuber melanosporum	1–2.5k

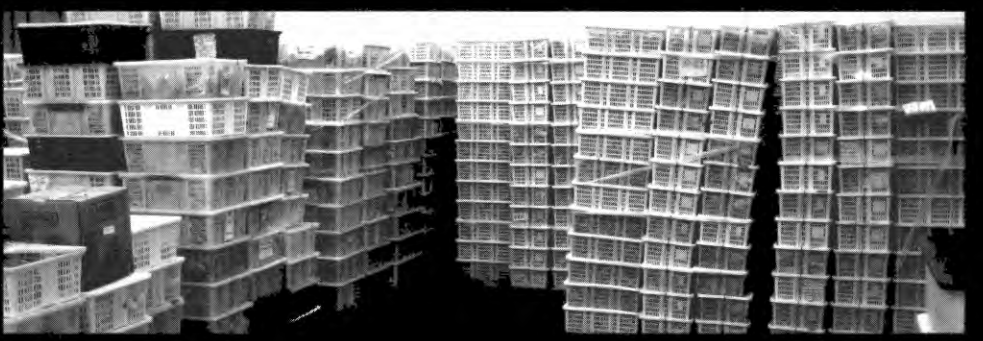
Commercial Foraging

Today, the collection of wild harvested mushrooms underlies a significant portion of the commercial mushroom industry. Though laborious, the practice is profitable enough for the hunters that have identified their spots to carve out a living solely on hunting fungi. Rumors abound of the business being dangerous and of dedicated hunters violently protecting "their" secret hunting grounds with firearms. However, according to the field research of Landon Cook, such claims are not well substantiated.[10] The Alliance of Forest Workers and Harvesters works to preserve prime mushroom patches from logging, offer language translation to harvesters, create ethical guidelines, and provide hunters with support in the face of racial profiling.[11]

Some commercially important mushrooms include Matsutake (which is heavily harvested in China); *Boletus edulis* in South Africa, Italy, and Eastern Europe; and *Lactarius deliciosus* in Eastern Europe. In Mexico, over 112 species are traditionally consumed or worked with as medicine. As part of this culture, foragers may travel 13–16 miles (21–26 km) in eight hours on foot to collect an average of 13.9 pounds (6.3 kg) from 2–10 sites. This effort represents nearly 20% of the overall income from agriculture and extra-agricultural activities in the region.[12] Many dedicated hunters travel with the flow of the mushroom fruiting season through the year. In North America, a common mycogration is:

Late August–September: SE Alaska
Early September–late October: Southern B.C.
October–early November: Washington to central Oregon
Mid-late November: Southern Oregon to Northern California
Early December–early January: Central California
Late January–early March: Southern California, Sierra Mountains, Cascade Mountains

The total annual global crop of wild harvested mushrooms is 400 million pounds (181 million kg), or about US$1.25–1.4 billion of commercial value. Combined, Europe, Asia, and the U.S. have created a US$12 billion per year wild mushroom industry. In the US, wild mushroom transactions may be the largest legal cash-based form of commerce.[13] In general, Germany and France are the biggest importers of wild mushrooms, though more than 90% of Matsutake harvests go to Japan.



the fifth branch on the Mycelium of Life. For although the quality of each individual's human-fungal-ecological relationship is so often defined by the number of species that one can name, when the next several generations are considered, such bragging rights quickly fall by the wayside. Ultimately, the mark of one's mycological brilliance should perhaps not be defined by the degree to which a person can see the fungi but, rather, by the clarity of the lens through which such a perspective is framed, reflected, and honored.

Recording Distribution

The simplest way to contribute to the collective knowledge of fungal patterns is to add your species account information to a distribution map of the fungi you observe and/or collect. Unlike the distribution of many plant species that have been thoroughly mapped across the world, the wanderings

of most mushrooms and lichens are hardly understood. This tracking can also help mycologists better understand which species are threatened or are being affected by changes in climate and soil temperatures. It can also help in the discovery of new species. This critical research is one aspect of fungal ecology that is the most accessible for any amateur mycologist to actively contribute to as a form of citizen science. Indeed, it is important that this kind of knowledge is passed on to future generations from the elders in the mycological community. At the institutional level, there is a rather low number of experts naming new species. Since the 1980s, a mere 50 authors have been responsible for 26% of the fungi described, several of whom are now dead or retired.[17]

The website Mushroom Observer, noted above for aiding in identification, is one site dedicated to tracking the distribution data of all fungal taxa. Likewise, the volunteer-based North American MycoFlora Project[18] is currently working to "produce a modern, comprehensive mycoflora of macrofungi for North America... [and] provide online keys and downloadable applications, up to date distribution maps, links to macroscopic and microscopic images, and links to nucleotide sequences and phylogenetic trees." An ambitious project, to say the least, but one whose fruiting is long overdue.[19]

Protecting Habitat

Refining distribution maps not only leads to an increased understanding of fungal ecologies, but also of the degree to which certain species are threatened across regions of land. If, for example, certain species are found to be in lower populations than previously estimated, their protection status can potentially be increased to threatened or endangered. This form of independent, volunteer-based fieldwork is critical for creating thorough surveys of habitats that have been sold for clear cutting or development. In Oregon, the organizations Bark[20] and The Blue Mountains Biodiversity Project[21] both perform such field surveys in proposed timber sales in search of contract violations. One of the most common forms of violations that they find is the presence of threatened or endangered plant or animal species in the sold area.

Mushrooms and lichens that are currently recognized as threatened around the world are listed in Appendix B. Local mycological or lichenology associations may also hold lists of rare species in your region, just as elders in the community may be able to offer a verbal history of changes in fungal diversity patterns that suggest species in need of protection.

The process for identifying endangered mushrooms and lichens is the same as with any species. If a potentially protected species is encountered, be sure to take thorough notes and extensive pictures from multiple angles that include the surrounding habitat. These photos are important for verifying claims, which can only be officially done by a certified specialist.

If the threatened species is correctly identified, its degree of protection can be somewhat subjectively interpreted. Under the Northwest Forest Plan that governs the forests of Oregon and Washington, the taxonomists that validate the identity of rare species can determine, on a case-by-case basis, if the site around a threatened species deserves protection based on its relative abundance locally. Where a species is in high numbers, despite generally having a low population regionally, its protection buffer may be incredibly small and not fully reflective of its ecological needs. Similar protection policies may be at work in your area. If you are interested in performing fungal field surveys for habitat protection, be sure to gain a solid understanding of the regulatory policies (and their loopholes) that guide their enforcement.

Preserving Aesthetics

If thoroughly dried, the normally ephemeral beauty of fungi can be preserved indefinitely, enabling their grace to extend to future generations of mushroom seekers. Drying is easily accomplished in a dehydrator set to a low temperature or by stringing fungi up high in an area that constantly receives dry, warm air. More delicate species are best dried in an airtight container along with a packet of silica crystals. Once the mushrooms are brittle, they can then be placed in an area that has relatively low humidity, so as to avoid rehydration of the tissue.

Alternately, mushrooms can also be preserved in jars of 70% ethanol or isopropyl alcohol. The mushrooms should first be wrapped in a paper towel soaked in the solution and placed in a sealed jar for two days. Afterward, the mushrooms are removed from the paper and submerged in a clean jar filled with the solution. Glycerin can also be added to the liquid at a rate of one teaspoon per quart to aid in preservation. Once preserved, the fungi can then be placed on a mantle, altar, dashboard, or in a mycurio cabinet of fungal wonders and other natural oddities.

Preserving for Identification

If you have collected multiple specimens of the same species, consider preparing them for storage in your local university's or mycological society's herbarium. Such specimens are critical for helping understand how a species' distribution pattern and morphology can change over time. Curated herbaria are good alternatives to private collections as they are usually environmentally controlled to provide for optimal storage, while also being publicly accessible. Each herbarium has slightly different requirements for submitting specimens, with most requiring extensive collection notes, such as those listed earlier in this chapter. For advanced techniques on collecting and preserving all types of fungi see *Biodiversity of Fungi: Inventory and Monitoring Methods* by Mercedes Foster and Gerald Bills.

Preserving Genetics

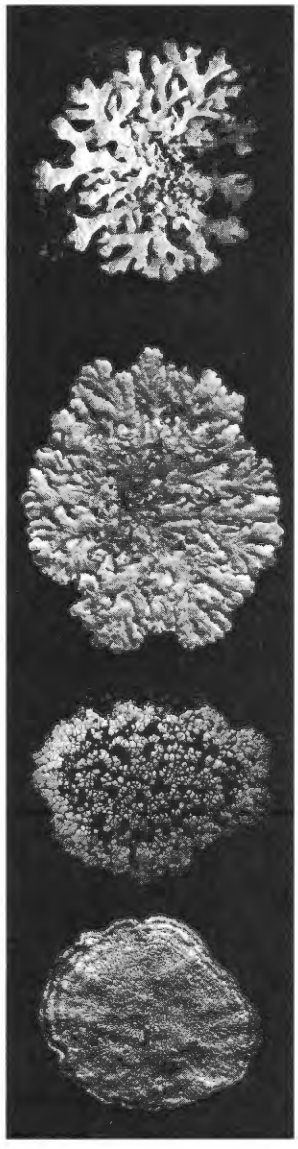
For the fungal cultivator, the preservation of a collection's genetics is an obvious application of one's skill set. As outlined in Chapter 8, storing cultures in sterile distilled water, or dried on grains or cardboard are a few preservation methods that require little maintenance or energy. For the non-cultivator, even the simple act of preserving spore prints provides a route toward protecting the diverse genetics of local fungal species and strains. Such bioregional spore and culture banks are a logical outgrowth of the modern seed saving movement, which seeks to ensure genetic diversity in the face of unmediated genetic modification and habitat destruction. But, unlike some seeds, dried spores can be stored for an unknown number of years, with the potential to retain their viability upon hydration (just as dried mycelium can). The preservation of fungal cultures is one of the simplest acts that Radical Mycologists can perform to communicate a cultural ethos of ecological respect, regeneration, and resilience to future generations.

Chapter Five

Radical Lichenology

By Nastassja Noell

Lichens are expressions of pure joy. Their variety of color, morphology, chemical constituents, and inexhaustible capacity for adaptability is proof that the living world is not purely utilitarian. Lichens remind us that life is art and that deeply integrating into one's environments is the most refined expression of that art. Lichens paint the rocks of the desert with living murals, drape the temperate forests with lace ribbons, and thrive in the harshest of climatic conditions. From Antarctic to tropical systems, from rainforests to deserts, lichens are ever-present, showing us a way of fungal being that is always exposed, always present. Humbly, they slowly grow by crystallizing sunlight and vapor[1] into delicate but resilient symbiotic systems. Inside the ecosystem of a lichen are most of the primary components of life: fungi, bacteria, algae, and cyanobacteria, all living in a discrete synergistic system that can rarely be synthesized *in vitro* but can withstand the extreme conditions of outer space.



Lichens form a terrestrial version of kelp forests and coral reefs. Like their cousins the aquatic algae, lichens absorb all their nutrients from their surroundings: the sea of vapor permeating the terrestrial world. Without a fungal partner, such a lifestyle would be nearly impossible for the algae in lichens. The fungal symbiont creates a thick protective skin around the algae to protect it from desiccation. In exchange, the algae gives the fungus photosynthesized sugars. And together, they form shapes and pigments that help them survive and thrive in their other-worldly surroundings.

This symbiosis of fungus and algae is thought to date back to the first ancestors of terrestrial life. As landforms diversified and developed, as mountains rose defiantly and weathered into soft hills, lichens have been patiently watching from their perches. Some contemporary lichens are over 5,000 years old—relics from a distant age. Lichens are the beholders of stories on landscapes and climate, if one takes the time to witness them clearly.

Though their slow and ancient nature lends to lichens being lost in the shadows of the larger members in their ecosystems, these fascinating beings are not static. Rather, they perform numerous mutualistic roles with bacteria, insects, rodents, ungulates, and humans. And there are four main reasons that humans work with lichens: as medicine, as a natural dye source, to monitor environmental health, and to study ecosystem biodiversity and dynamics.

What is a Lichen?

A lichen is not a singular organism but a symbiotic relationship between a fungus and algae and/or photosynthesizing cyanobacteria. What we see when we look at a lichen body—technically known as the *thallus* (pl. *thalli*)—is a complex structure comprised largely of these partnered organisms.

The Mycobiont

Over 95% of the lichen thallus is the fungal partner, or *mycobiont*. Compared to the underground mycelial networks of wild mushrooms, the fungal mass of a lichen lives almost entirely exposed to harsh conditions that would kill most non-lichenized fungi. The fungus protects the lichen from the harsh above-ground environment by building a *cortex*, a dense layer of fungal tissue that prevents water loss, and a *medulla*, a fluffy, hydrophobic network of hyphae in the interior of the lichen. Inside the thallus is where most of the lichen magic happens, from the production of powerful medicinal compounds to the mind-boggling interplay between bionts.

Curiously, research on the 14,000 known species of lichenized fungi (around 3,000 species are thought to be currently undiscovered) demonstrates that lichen mycobionts do not form a common clade on an evolutionary tree (i.e. they don't have a common ancestor). Rather, the lichen relationship seems to have independently arisen at least five times over the eons, demonstrating the success of this relationship and serving as a clear example of convergent evolution. These relationships can also shift over time, as shown in genetic analyses that suggest some major lineages of currently free-living fungi were previously lichenized.[2] About one-fifth of all known fungal species are lichenized and nearly all of these fungi are obligate symbionts. Over 98% of lichenized fungi belong to various branches of the Ascomycota. There are some lichenized Basidiomycetes; most of these are found in tropical regions, but some live in boreal and temperate regions.

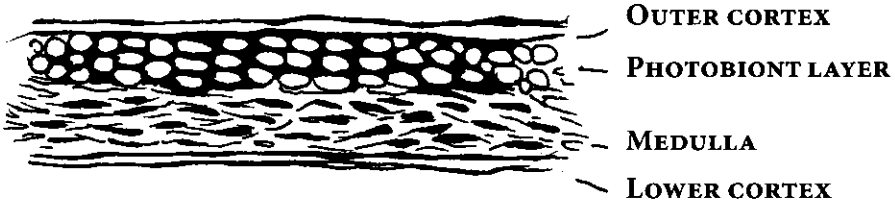


Diagram of a typical stratified lichen.

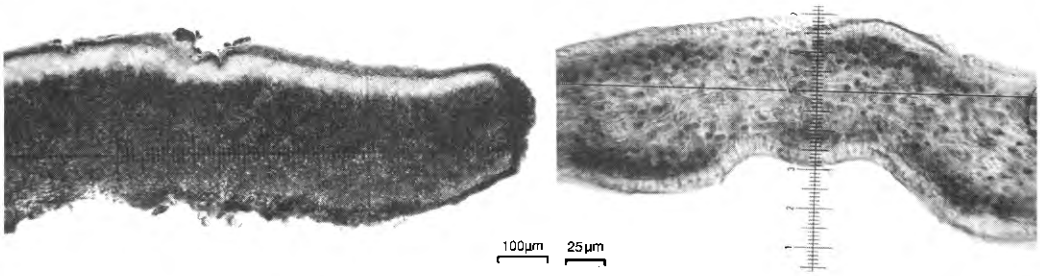
The Photobiont

The photosynthesizing partner (*photobiont*) is what makes the lichen an autotrophic organism. About 30 species across two kingdoms are known to act as the primary photobiont within lichens. Most photobionts are eukaryotic green algae species, though about 10% of lichens have a prokaryotic cyanobacterium as a photobiont. Approximately 4% of lichens contain both algae and cyanobacteria as photobionts.[3]

Lichens that contain a green alga as their photobiont are called *chlorolichens*. Lichens with cyanobacteria as their primary photobionts are called *cyanolichens*. *Tripartite lichens* have both types, with the cyanobacteria generally being contained within a specialized structure called a *cephalodium*. Cephalodia are not well studied, but they seem to help maximize nitrogen fixation in the thallus in a manner similar to the anaerobic gas chambers of root nodules in legumes.

In the lichenized state the photobiont's natural life cycle is usually suppressed. Filamentous algae and cyanobacteria are often deformed into shorter filaments or unicellular states, and cyanobacteria cells are typically larger than in the free-living or cultured state. Sexual reproduction is also suppressed within the lichen, and it is assumed that most algal growth in the lichen occurs primarily by asexual means. But asexual reproduction is not always as simple as cell division and may include sporulation by flagellated motile zoospores, which are occasionally found within the lichen thallus.[4]

Structurally, the primary photobiont forms a green or blue layer underneath a protective *outer cortex* of dense hyphae. This outer cortex acts as the glass roof of a greenhouse of sorts and regulates gas and moisture exchange, providing a homeostatic environment for the photobiont to thrive. This photobiont layer is nested within the upper part of a loose, cottony, hydrophobic layer of hyphae called the *medulla*.



(Left) Cross-section of a chlorolichen. Note the distinct stratification of the green algal layer and the gray fungal medulla, as well as the thickness of the outer cortex (the white tissue above the green algal layer that is melanized brown at the very edge).

(Right) Cross-section of a cyanolichen, the Jelly Lichen Leptogium lichenoides. *Note that the cyanobacteria and the medulla are intermixed in the interior and the outer cortex is very thin.*

The Relationship Between Bionts

While the fungus comprises the bulk of the thallus, it is by no means the dominant partner. For example, the photobiont is just as responsible as the mycobiont for determining the shape of the thallus that will maximize photosynthesis. These shapes take a variety of forms, often reflecting the lichen's habitat and substrate. They may be leaf-like structures clinging to hillsides, or flat crusts on rocks that capture light coming from one direction in a way that is akin to solar panels. Or they may be hair-like curtains draping from tree branches that can capture diffused light in misty habitats, or a blend of all of these shapes. As with mushrooms, it is the unique blend of these and other features that define a given lichen species.

Lichens have been found in recent years to be comprised of much more than just two or three partners. More like a miniature ecosystem, a lichen thallus can also contain hundreds of other microbes and fungi. These organisms include *epibiont bacteria* that live on the surface of lichens and may play key roles for cell wall function and nitrogen fixation.[5] There are also *endolichenic fungi* that seem to be cohabitating inside the lichen thallus performing unknown beneficial functions. Endolichenic fungi cannot be seen with normal light microscopes and do not create symptoms in the lichen. Other fungi grow on the surface of lichens. Some of these *lichenicolous fungi* have been found to be parasymbiotic, often with unknown relations to the lichen, while most others, such as *Carbonea* species, are purely parasitic. This group includes some odd parasitic Basidiomycete fungi that grow on lichens, such as *Biatoropsis usnearum* and *Cystobasidium usneicola* which form galls on *Usnea* species. Most of the 3,000 known species of lichenicolous fungi are obligate to a particular genus or family of lichens. However, as our understanding is currently limited about their range, distribution, and biodiversity, more research is needed to form a more thorough analysis of their roles and niches.

Some lichenized fungi are transiently parasitic. In the early phases of their life cycle they live on or within an established lichen thallus in order to take algae from the lichen host. In some instances, this new fungus-photobiont pair may even take over the original lichenizing fungus and form a completely new type of free-living lichen.[6] Phylogenetic evidence suggests that a tremendous amount of algal switching occurs between lichens.[7] Further, as there are so few photobiont species compared to mycobiont species, it has been suggested that the lichenized fungi may be suppressing the algae's ability to reproduce in an effort to stabilize their genetics and reduce speciation events. This might explain why *Trebouxia* species are not found free-living, despite being the most common photobiont in lichens. *Trebouxia* may have evolved to be dependent on the lichen biome and is only able to survive and procreate through the algal swapping between lichen thalli. As lichenology is still in its infancy—much more so than mycology—more research needs to be done to determine where the line is drawn between what does and does not constitute the lichen microbiome.

Lichen Needs

Lichens crystalize airborne water and nutrients into complex molecular arrangements that are used to build their bodies, construct secondary chemicals, and create microhabitats that favor their niche. While lichens have adapted to nearly all terrestrial habitats, there are a small number of ecological constraints that lichens must creatively respond to in order to thrive:

- **Water:** Unlike most plants, lichens do not have a vascular system that conducts water throughout their thallus. Rather, lichens absorb water from mist, dew, rainwater, waterfall spray, ocean air, and the humid microclimates created by moss. Whatever is in this water (e.g. salts, heavy metals), the lichen will absorb.
- **Nutrients:** Lichens lack true mycelia in the sense that lichen hyphae do not penetrate the substrate that they grow on in order to absorb nutrients. Most of these nutrients are obtained from rainwater and airborne particulates. A smaller amount are provided by water that has leached nutrients from deciduous tree bark, limestone boulders, or other substrates and subsequently dripped onto the lichen. Some species prefer certain nutrient sources. *Nitrophiles* are lichens that thrive in areas impacted by nitrogen pollution, such as agricultural areas or near popular bird roosts. *Calciphiles* thrive on calcium-rich substrates, such as limestone or calcium-rich soil. The pH of the substrate or water source is critical as most species have adapted to a particular pH range. Limestone and deciduous tree bark generally have a high pH; coniferous trees and granitic rocks tend to be nutrient poor and have a low pH.

Seeing Lichens

Lichens embody the principle of symbiosis at many different scales, yet their misrepresentation throughout history has led to their ecological importance being overshadowed by shortsighted descriptions of their internal and external dynamics. Depending on how one chooses to perceive Nature, the lichen symbiosis is often described in one of three ways:

Reductionist Perspective

A lichen is a symbiotic organism, composed of an alga or cyanobacterium and a fungus. This relatively bland description—if indeed it says anything at all about the other organisms living in the lichen thallus—treats each biont as an isolated entity that reacts predictably and mechanically to the other bionts one at a time. The reductionist extracts a fungal spore, tries to grow it in isolation in a plate of agar, and is stumped when the resulting undifferentiated slime refuses to magically turn into an elaborate and colorful lichen when she drops an algal cell into the dish.

Mycocentric Perspective

A lichen is a dietary choice of a fungus—a fungus that discovered agriculture. In this perspective, the mycobiont is said to create a structure that is similar to a greenhouse, solely to provide a beneficial growing environment for the algae that keeps it alive. Like a good farmer, the mycobiont produces sunscreen-like compounds that protect the algae from harmful UV radiation during dry periods, anti-herbivory and anti-microbial compounds that reduce predation, and a three dimensional structure that regulates moisture and gas levels within the lichen in response to the growth needs of the algae. The algae, in this perspective, is scarcely distinguishable from the substrate or air surrounding the lichen; it supplies photosynthetic sugars to the fungus and that's about it.

Systems Perspective

A lichen is an ecosystem, it is an emergent property. In the systems perspective, a lichen is understood to be entirely different than the sum of its constituent organisms. Such cumulative associations are found in the experience of consciousness arising from the random firing of individual neurons and in the collaborative power of a worker's cooperative or social movement. The systems perspective of lichens requires a conceptual leap that challenges traditional biological concepts of species and the linear phylogenetic arrangement of the Tree of Life. Within the systems perspective, the ecology of the lichen symbiosis is emphasized over the individual roles of each biont, and the boundaries between the bionts blur. Lichens are understood as ecosystems, where both autotrophs and heterotrophs are present and in balance, and gas and nutrient exchange between the two bionts creates a miniature biosphere that regulates the temperature, moisture, and light and gas levels of the system in relation to its surrounding environment. The shape, features, colors, and morphological particularities of lichens are a dynamic and complex interplay of the bionts, the lichen, and the surrounding ecosystem.

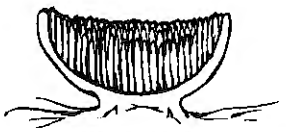
- **Substrate:** Given enough time, lichens can grow on nearly any surface, from rotting couches, to rusting metal, to evergreen leaves and desert soil. But the finely tuned nutrient, water, and light requirements of most lichens tend to limit a species' growth to one type of substrate. *Epiphytes* grow on trees or shrubs, *saxicoles* grow on rocks, and *terricoles* grow on soil.
- **Light:** Light is critical to the generation of photosynthates and, indirectly, the secondary metabolites that protect the lichen from parasites and herbivores. Lichens usually thrive in areas that have intense to diffuse light, however many species, such as the pin lichens, are adapted to grow in darker habitats like the underside of logs or in rock crevices.
- **Water and light regimes:** Unlike most fungi and plants, lichens are *poikilohydric*, meaning they can readily withstand desiccation. During dry periods, lichens go into a dormant state that can last more than 100 years. When these dormant thalli are rehydrated they can return to life within minutes and begin photosynthezing. During periods of darkness the lichen cannot produce additional photosynthates. If the lichen does not enter dormancy via dessication it will eventually run out of the materials to produce secondary metabolites, making it more susceptible to parasitic fungi and bacteria, particularly if temperatures are warm and the climate is moist (accelerating the fungal metabolic processes).

Lichen Chemistry

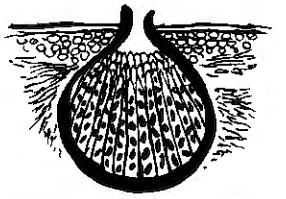
The range and complexity of the chemicals and secondary metabolites produced by lichens is almost unparalleled by other similarly sized groups of organisms. Most lichen species have a distinctive chemistry that tells a story about the habitats they call home, the challenges they've encountered, and their adaptive resilience. Many of the pigments that give lichens their range of colors have been found to act like a sunscreen, reflecting or absorbing light (e.g. atranorin), while other lichen chemicals stored in the interior medulla of the lichen have been found to have anti-herbivory properties against snails (e.g. gyrophoric acid). Most lichens also have antibiotic properties that are effective against fungal and bacterial parasites (e.g. usnic acid). These compounds can be used as medicines for humans. While chemistry can be used to distinguish lichens at the species level, most chemicals are not limited to a particular genus or family. The vast multitude of secondary chemicals can be found within most families or orders of lichens. The phylogenetic implications of this may be suggestive of genetic bottlenecks, such as during the K-T extinction, or of the horizontal transfer of genes between different groups of lichens.

The Reproductive Structures of Lichens

Though the algae and fungi in a lichen cohabitate, they do not share DNA. Both organisms reproduce independent of the other, and a lichen as a whole may have multiple ways of replicating itself. The mycobiont tends to reproduce much like other fungi, often through the production of sexual spores and/or asexual conidia. The Ascomycete lichenized fungi have sexual reproduction patterns that tend to reflect those of their mushroom-forming kin, especially the Cup Fungi in the order Pezizales. In Ascomycete dominant lichens, the spore producing ascomata are generally apothecia or perithecia. Some Basidiomycete lichens do exist, however these are rare and often mistaken for mushrooms. The fruiting body structure in a Basidiomycete lichen is often similar to an agaric mushroom, however the mycelium and associated green algae form a distinct, superficial vegetative thallus (e.g. the basal scales of *Lichenomphalia hudsoniana*). The exception is the basidiolichen *Dictyonema s.l.*, which looks and feels like a polypore mushroom, but the photobiont lives in the interior of the thallus.



Apothecia.



Perithecia with asci filled with sexual ascospores. Pycnidia look similar but contain asexual conidia.

After sporulation by the ascomata or basidiomata, the spores grow independently for a short while until an appropriate photobiont is found. These spores take on a variety of shapes, sizes, colors, and forms. As with mushrooms, the general spore types are usually consistent across genus or family. Most lichens also have asexual fruiting bodies (*conidiomata*) that produce conidia. In some species, conidia have been found to act as spermatia, fertilizing another lichen through a structure known as a *trichogyne*.

Interestingly, most lichens also feature one or several methods for asexual cloning of the lichen itself. Instead of, for example, producing new spores with unique DNA sequences, these lichen clones are little bundles of fungal hyphae containing several photobiont cells. These bundles, called *diaspores*, bud off and fall away or are carried by the wind to new habitats where they serve as "seeds"—cottony clones of the mother lichen—that will eventually grow to be a new thallus. Diaspores can be dispersed hundreds of miles on the feet of traveling birds and in the air currents of the upper atmosphere, or more locally on the backs of insects and animals. Often the diaspores simply fall from the mother lichen to establish on a lower branch or below a host boulder.

When a diaspore lands on a suitable substrate and the right moisture and nutrients are present, it will first grow rhizomorph-like structures over the surface of the substrate. From this structure the thallus' tissues will begin to grow from the center outwards on top of the substrate, forming the cortices, the medulla, and a layer of photobiont cells. Diaspores come in two main forms:

- **Isidia:** These diaspores grow from within the medulla and push up through the cortex, bending the cortex around the diaspores, forming a protective cortex that then breaks off in finger-like pieces.
- **Soredia:** These diaspores lack any protective cortex. They are granular outgrowths of the medulla that grow up through openings in the cortex called *soralia*.

Isidia Soredia

Diaspore-producing lichen species have distinct morphologies that aid in their identification. Lichens that produce isidia will not produce soredia, and vice versa. The diaspore type and location of origin are significant characteristics that likely reflect speciation events in the evolution of a particular group of lichens. Most sorediate and isidiate species will also occasionally still produce viable apothecia (in addition to their usual asexual diaspores), however there are a few species (e.g. *Lepraria spp.*) that have never been observed in the sexual state. Very rarely one will encounter sorediate or isidiate forms of species that normally do not produce diaspores. This terminology might be confusing at first, but just remember that diaspores contain both algal and fungal symbionts and thus reproduce the whole lichen as a clone, while spores reproduce only the mycobiont.

Lichen Phylogenetics

The Mycobiont

About one-fifth of all fungi are lichenized and nearly all of these fungi are obligate symbionts to the lichen: they cannot carry out their entire life cycle without their symbiotic partner. Although all lichens share a similar nutrient acquisition strategy of deriving photosynthates from a phototrophic organism, lichenized fungi do not form a common evolutionary group, or *clade*. Depending

on the researcher, around five clades of Ascomycete fungi are considered lichenized, and some of these clades include both lichenized and non-lichenized fungi.[8] Additionally, phylogenetic research suggests that some lineages of non-lichenized fungi were previously lichenized (e.g. the chemically powerful genera *Aspergillus* and *Penicillium*[9]), suggesting that lichenization is not necessarily genetically predetermined, but rather a system built by the bionts that can be abandoned in certain situations, such as has been found in some *in vitro* culturing situations.

Most lichenized fungi (about 98%) belong to various branches of the Ascomycota, but little is known or speculated as to what characteristics make ascomycetous fungi more favorable to the lichen symbiosis than other fungal groups. To turn the question on its head, we might ask, why have lichenized Basidiomycetes not evolved and diverged with the same exuberance as their ascomycetous brethren? Basidiolichens make up only 2% of all lichens.[10] The answers to these questions remain highly speculative at best.

The Photobiont

About 100 taxa of algae and cyanobacteria are known to act as photobionts within lichens.[11] Although there are relatively few species of photobionts in comparison with mycobionts (ca. 17,000 taxa), the potential photobionts range across different kingdoms. The favorite photobiont for lichens is by far the eukaryotic green algae, which belong to the Plant Kingdom, while the less prevalent prokaryotic cyanobacteria are part of the Eubacteria Kingdom. The Verrucariaceae lichens—some of which are renowned for growing on tidal rocks where nothing else can grow—include species with a red algal photobiont from an unknown and unresolved kingdom, and one species with a brown algal photobiont from the Chromalveolata Kingdom.

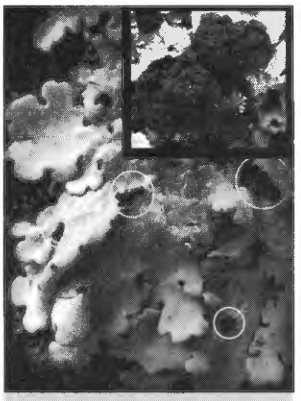
Proper identification of a photobiont requires culturing in order to see the distinguishing morphological features associated with different parts of its life cycle. Due to the unstable taxonomy of algae and bacteria, most photobionts are known to genus at best. Due to these limitations, there may be many unnamed species or even genera of photobionts and a far greater diversity of photobionts than is currently understood.

Coevolution of photobionts and mycobionts has not yet been demonstrated by phylogenetic research, rather it appears that specialization is unidirectional. Molecular research suggests that lichenized fungi are extremely faithful to a particular set of photobiont species and evolved to adapt to that species or species group. The reverse does not hold up in molecular analysis: while photobiont species are found to associate with a wide range of lichens, most are also found free-living. Existing phylogenetic research does not yet demonstrate that lichens harbored their evolution and diversification. But there are exceptions, including the green algae *Trebouxia* (a huge exception considering it is the most common lichen photobiont) and *Myrmecia*. These algae are rarely found free-living and the lichen symbiosis appears to be their primary mode for growth and dispersal.

The Classification of Lichens

For various reasons, lichens are taxonomically classified by the fungal partner, not the photobiont, nor the symbiosis of the two entities. This taxonomic system is challenged by some lichenologists who emphasize that a lichen is the combination of two genomes, thus the sum is distinctly different than the single fungal genome. Taxonomic classification based upon symbioses between two or more organisms challenges the linear-hierarchical system of Linnaean taxonomy. An emergent classification system would have to be born from the old standard system.

Recent research is showing that there is also a range of associated bacteria whose relationships to the lichen symbiosis are currently unknown, but they are very specific to the lichen thallus.[12] The bacterial flora on the surface of a lichen is often distinctly different from the flora of the surrounding soil. Research into the roles of these organisms in the lichen symbiosis is an emerging area of research.



The white foliose lichen is built by the same fungal species as the brown corraloid Dendriscocaulon *lichen (insert). Why do they look so different? They have two different photobionts. Until traditional taxonomic concepts can incorporate co-dominance of bionts, these lichens are considered the same species:* Lobaria amplissima.

Photosymbiodemes: Why Photobionts Matter

Photobionts are not merely passive photosynthesizing cells that are subordinate to their fungal superiors. Hardly. Subordinance is rare outside the animal kingdom. Although the extent to which different photobionts drive lichen morphology is not clear, there are some striking examples of photobionts that completely change the structure and function of a particular lichen symbiosis. A good example of this is found with the branching fruticose cyanolichens in the genus *Dendriscocaulon*. Until recently, *Dendriscocaulon* was considered taxonomically unrelated to the foliose (leaf-like) genera *Sticta* and *Lobaria* because the morphologies of the two groups are so strikingly different. But recent molecular research has shown that the mycobionts in Dendriscocaulon are identical to some of those also found in the *Sticta* and *Lobaria* genera; the only difference is the photobiont. These trans-photobiont pairs, called *photosymbiodemes*, calls the concept of a mycocentric lichen taxonomy into question. For this puzzle to be adequately resolved, the phylogenetic Tree of Life would have to anastomose, creating a Mycelium of Life in which species are the nodes.

Lichen Biodiversity and Bioindications

From coastal deserts to tropical rainforests, from temperate deciduous and coniferous forests to prairies and talus slopes, anywhere you look, lichens thrive in vast numbers. They are so globally abundant that 6% of the Earth's land surface is estimated to be covered in vegetation dominated by these miniature ecosystems.[13] Yet, despite their ubiquity, it is surprising to find that only a few lichen species are globally distributed.

With no roots, mycorrhizal structures, wings, or feet, lichens are specially adapted to the quality of the air and type of climate that surrounds them, as well as the structure and nutrient cycles of their habitat. Worldwide, the highest biodiversity of lichens tends to be found in areas with a mosaic of diverse habitat types, different levels of continuity (e.g. ancient forests mixed with various seral stages of forest), and, of course, clean air. In general, the more diverse the topography and potential substrates, and the more pristine the habitats, the greater the lichen biodiversity. Thus, some of the best lichen hotspots in the world include the Great Smoky Mountains of southeastern United States, the Yukon of Canada, the tropical mountain systems of the northern Andes, the Himalayas and the Central American highlands. Other optimal sites include temperate rainforests in northeastern China and the Pacific Northwest of the United States, the forest and bogs of northern Ireland and Iceland, and southern Chile and Argentina. Even Antarctica hosts at least 484 species of lichens; of these more than 60 are not found anywhere else in the world.

In many of these areas *oligotrophic* lichens tend to dominate. These species prefer low levels of nutrients in the air and water, making their presence a strong indication of pristine air. These habitats tend to be rather stable and homogenous, so lichen biodiversity tends to only be increased by small-scale disturbances, such as a small fire or the falling of a large tree. A mosaic of small, isolated disturbances help increase light into the forest or release ash-borne nutrients into the canopy of trees. Both of these events can help increase lichen establishment and growth.

Conversely, large-scale disturbances greatly threaten lichen health and diversity. This is seen most clearly in urban centers—our modern "lichen deserts"—where air pollution and the destruction of habitats is directly correlated with a lack in lichen diversity. Most lichen species are so sensitive to the effects of acid rain and heavy metals that they will slowly disintegrate and die when exposed to the air around industrial areas. Some pollution-tolerant macrolichens, such as *Physcia* species or the bright orange species in the genera *Xanthoria* and *Xanthomendoza*, are often the only species found in heavily polluted areas, and their dominance is usually a clear indication of low air quality.

The distribution ranges of different lichen species also provide interesting insights into not only lichen biogeography, but also into the history of a place. Some lichens are endemic to very small areas, suggesting they are relics of a Pleistocene climate or remnants of a rapidly disappearing hab-

itat. The presence of slow growing pin lichens often indicates that a forested habitat has undergone little disturbance over a period of decades to centuries, and thus most species of pin lichens are associated with older growth forests. In desert environments, soil crust lichens have successional stages that correspond with the increasing stability of the soil. This creates a positive feedback loop whereby primary succession soil crust lichens create the habitat required by secondary and tertiary succession soil crust lichens.

Lichen distribution patterns also give us a look back into geologic time. For example, the genus *Heterodermia* is most diverse in southeastern United States and eastern Asia, strongly suggesting that their range was continuous during the Arcto-Tertiary geoflora, when the Appalachian mountains of eastern North America formed a contiguous landscape with modern China.

These responses to ecological variables make lichens strong bioindicators of climate and climatic regimes, air quality, acid rain levels, and the continuity of a habitat both spatially and over time. As such, a variety of biomonitoring methods can be employed to measure anthropogenic impacts on lichens and their surrounding environment. These skills are discussed in the Citizen Science section of this chapter.

Lichens Being

Within terrestrial ecosystems around the world, lichens co-create ancient temperate forests and add to the stoic resilience of desert ecosystems. These small creatures are not passive members of our local habitats, but critical ecosystem drivers.

In Deserts

Desert lichens form some of the most striking displays of a symbiotic relationship between an ecosystem and organism. In undisturbed desert landscapes, lichen soil crusts form a living skin: a mosaic of living biological soil crusts (biocrusts) that hold soil particles together and paint the desert floor in a pinnacled topography of yellow, white, pink, brown, green, and black biocrusts. This living skin is composed of lichens, moss, cyanobacteria, bacteria, actinomycetes, and fungi, together forming their own miniature ecosystem.

Biotic soil crusts on the Colorado Plateau, Canyonlands, Utah, USA. Notice the texture and height of the crusts compared to the worn down trail that weaves through them.

Biocrusts are vital for the desert ecology as they bind together surface soil particles and precious organic matter into a biological crust that is usually at least several millimeters thick. This living crust stores carbon to create organic matter. Jelly lichens, such as *Collema tenax*, also fix nitrogen. But the biocrust network goes beyond the production of essential nutrients: biocrusts create a state of homeostasis that supports the restoration and structural capacity for an arid ecosystem to thrive. And they do this in a way that is similar to the skin of humans:

- **UV protection:** The sunscreen-like pigments of lichens scatter or absorb UV radiation, protecting sensitive microfauna and microflora from the DNA scrambling effects of the sun.
- **Erosion control:** The biocrust's sticky photosynthates and the hyphae of fungi,

Don't bust the crust.
—U.S. National Park Service

actinomycetes, and lichens bind soil particles together a couple of centimeters deep beneath the surface of the soil. When intense precipitation occurs, the biocrust rapidly absorbs the water, sending it deeper into the soil through the hyphal web, while at the same time allowing excess water to slide across the surface of the biocrust. During heavy rain events, bareground areas that are covered by biocrust are able to retain nearly all their soil, nutrients, and organic matter relative to areas lacking biocrusts.

- **Infiltration:** Precipitation events in arid lands are precious, and the pinnacle-and-valley topography of biocrusts form miniature rainwater catchments that enable water to infiltrate the ground and reach the deep roots of native plants and shrubs. The height of the pinnacles and the depth of the rainwater catchment valleys can vary from 1–10 centimeters or more, depending on the extent of frost in the region and the length of time that the area has been undisturbed by heavy grazing or trampling.
- **Reservoirs of biodiversity:** The topography of the soil crusts create humid microclimates that nurture the seeds of native plants, insects, and microfauna, which are also supported by the nutrients produced by the crusts.[14] Further research into the miniature webs of life that are supported by biocrusts is greatly needed.
- **Soil organic matter:** In arid lands, most organic matter is limited to the areas around shrubs and perennial grasses, leaving large, barren interspaces. Biocrusts fill these interspaces and create a thick (1 cm or more) layer of fixed carbon and organic matter that feeds and protects the soil microfauna, yielding a more fertile desert that can harbor greater biodiversity.
- **Soil nitrogen:** Nitrogen is a limiting nutrient in most ecosystems, but particularly in deserts where overall diversity of nitrogen-fixing plants can be quite low and atmospheric input from lightning is easily lost. Biocrusts at various stages of development have been found to contribute 2–365 kilograms of nitrogen per hectare each year.[15] One of the most productive biocrust species is the jelly lichen *Collema tenax*.

In Forests

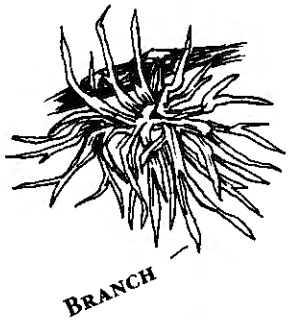
Lichens are probably best known for their majestic displays in temperate forests around the world and their strikingly bold presence in tropical forests. Where there is clean air and moisture, forest lichens thrive and are integral members of their ecological communities.

- **Protection:** Many lichens create anti-herbivory chemicals to protect themselves from insects. This protection is also imparted to the trees on which they grow. This is notably important for young hardwood trees, which are susceptible to insects sucking on their sweet cambium juice. In clean air forests, smooth barked hardwood trees are usually covered with a mottling of white, green and blue crustose lichens that grant the tree an anti-herbivory shield.
- **Structural:** Lichens form a variety of canopy and surface structures which moderate and enhance humidity and temperature, helping support other epiphytes, native plants, insects, arthropods, and microfauna. Canopy lichens and the biotic community of forest canopies help to create a furry skin over the surface of forest ecosystems that traps in humidity, stabilizes temperatures, facilitates the resilience of forest ecosystems, and even influences the precipitation patterns of downwind ecosystems.
- **Nutrient sponge:** Lichens function as biological sponges that absorb nutrients from the air. In coastal areas, tufts and dangling lacy nets of fruticose lichens trap and absorb the nutrient content of ocean air, slowly releasing these nutrients into the terrestrial environment by rainwater leeching or decomposition.
- **Carbon and nitrogen fixation:** All lichens fix carbon, and many also fix nitrogen. Lichens in temperate rainforests contribute up to 50% of the nitrogen budget

Along with the anti-herbivory layer provided by crustose species, the foliose lichens on older trees provide habitats for beneficial insects, thereby nurturing insect biodiversity, which in turn helps combat detrimental pests.

for the forest. Nitrogen is a primary limiting nutrient in most ecosystems.

- **Food web:** Lichens provide critical winter forage in temperate to boreal forests. Horsehair Lichens (*Bryoria spp.*) are the primary winter forage of keystone species, including woodland caribou. A variety of small mammals depend on them for food as well.
- **Insects:** Insect-lichen associations are relatively unknown. Some insects such as Lacewings use lichens as camouflage, but there are likely many more intersections to be discovered.



Fruticose lichen.

Identifying Lichens

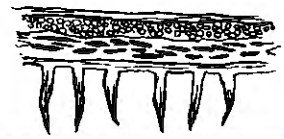
Before one can begin to work with lichens, it is essential to be able to first learn how to identify them. Identifying lichens is one of the most rewarding ways of engaging with lichens for it not only enhances personal and ecological resiliency but also increases one's connection to a habitat. As you learn how to identify lichens, more and more species begin to reveal themselves. A forest that previously looked like a wash of only one or two lichens soon turns into an ecosystem covered in hundreds of species.

Luckily, learning to identify most of the larger lichens is not too difficult and requires little equipment. If you're an herbalist, a good 10x or 20x loupe, field guide, and practice differentiating between look-alike species is all you will need. If you're an artist and want to collect dye lichens, you'll also need to do spot tests, as described later. If you're a citizen scientist doing environmental monitoring you'll probably also want a dissecting scope in order to identify lots of different species within a shorter period of time. And if you're a naturalist measuring total biodiversity, you'll eventually also want a compound microscope and the chemicals known as P and I.

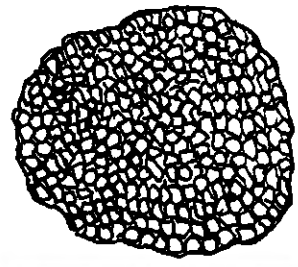
Identifying lichens first begins with determining the overall structure of the lichen, generally classified by the following three forms:

Foliose lichen.

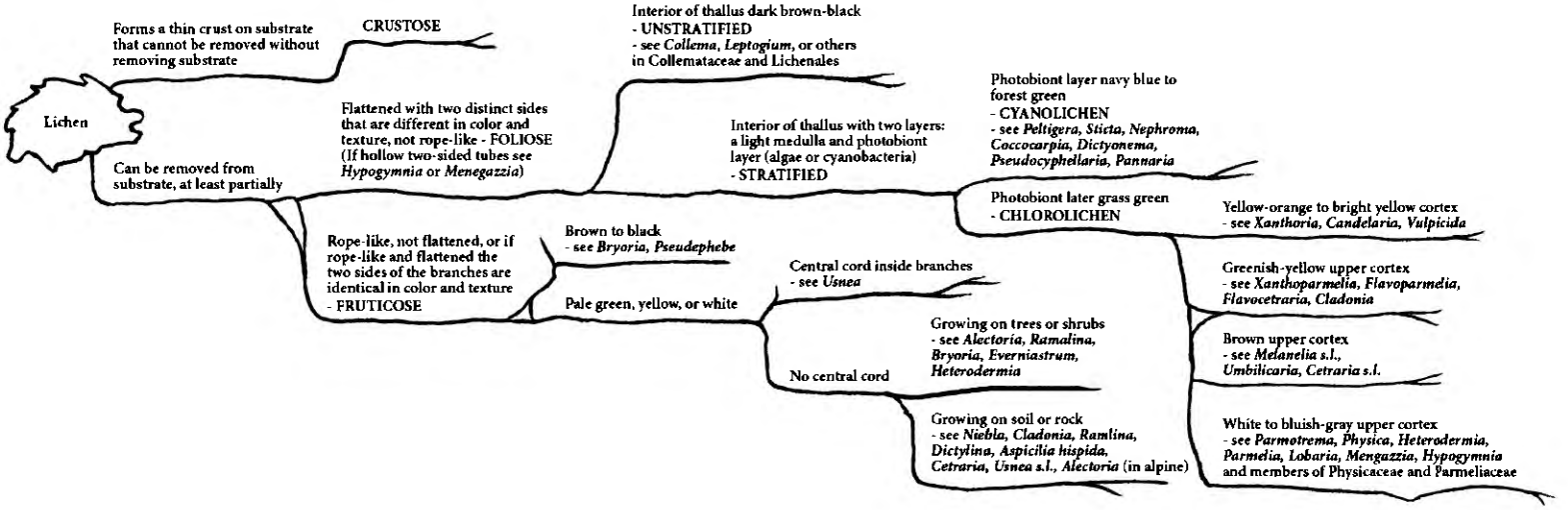
- **Fruticose:** These lichens have a tree- or beard-like form and are found in the greatest abundance growing in temperate rainforests. They tend to hang from trees where their large surface area is able to absorb as many nutrients and as much water from the air as possible. In more arid forests or areas with air pollution issues, fruticose lichens are often low in abundance and diversity. Unique features of fruticose lichens include *branches* and a uniform *outer cortex* (no distinction between upper and lower cortex is possible).
- **Foliose:** Foliose lichens are flatter and more leaf-like. They come in a wide range of shapes and sizes and are often found in the greatest abundance in moist temperate forests on the bark and branches of trees or on top of moss at the bases of trees and rocks. Most are attached to the substrate by *rhizines* (short root-like structures) and the thallus usually forms a *rosette* (rose shapes), where each section is called a *lobe*. Lobes can be elongated like fingers or squat like rose petals. Lobes that are smaller than 2 millimeters in length are called *squamules*; lichens with many squamules are called *squamulose*. Unique features of foliose lichens include lobes, differentiated upper and lower cortices (usually both are present), and rhizines.
- **Crustose:** These lichens are the most diverse group of lichens. They are found growing in all habitats, from the bark in tropical rainforests, to the soil of arid deserts, to frigid rocks in Antarctica. These lichens grow along or within the surface of their substrate, forming a living skin that facilitates water absorption and erosion prevention in desert habitats, while also providing an anti-herbivory shield for thin barked trees in temperate and tropical forests. Unique features of crustose lichens include an upper cortex (no lower cortex) and *areoles* (the tile-like subunits making up the thallus of many crustose lichens).



Rhizines.



Crustose lichen.



Basic lichen identification flow chart.

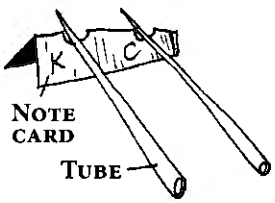
The Lichen Rainbow

Are lichenologists colorblind? Sometimes it sure seems like it! Describing the colors of lichens for identification purposes is a highly subjective and rather contentious topic among both amateurs and professionals. Is a lichen containing usnic acid called yellow, or yellow-green, or pale green? Ask three lichenologists and you might get three different answers. Similarly, a lichen containing the compound atranorin may be called blue by one person or white by another. It's all a bit ridiculous, but the matter is more confounded by the fact that lichen colors tend to vary when they are wet, dry, shaded, or exposed to the sun. Thus, some tips are offered to aid in determining a lichen's color:

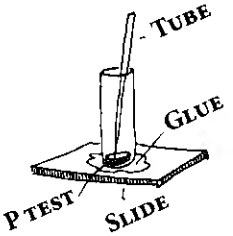
- Try to ID lichens only when they are dry. This is when their pigments are most visible and consistent.
- Learn to recognize lichen pigments instead of colors. Begin associating the color you see with the chemical produced by the lichen, that way you can learn the range of color variation of "usnic green," "atranorin gray," etc.
- When collecting lichens remember to note if the lichen was in a shaded location. Lichens exposed to less sunlight produce less pigment and are thus more pale or almost green colored.

Spot Tests

As with identifying mushrooms, proper identification of a lichen may require the use of color change-inducing chemical reagents. This process is slightly different from that of working with mushrooms, but with some practice it can often be done quickly in the field. The materials for spot tests include:



- **2–4 small glass containers:** These are for holding the chemicals. I prefer glass tincture bottles with eyedroppers that seal at the top.
- **Chemical application device:** I prefer glass capillary tubes, others use a dissecting probe. Eyedroppers apply too much chemical, producing inaccurate reactions.
- **Razor blade**
- **Dissecting microscope or large magnifying glass**
- **Chemicals:** The most commonly used chemicals for lichen identification are K (10% potassium hydroxide [KOH]) and C (normal household bleach). As you get more comfortable with lichen identification you will want to add E (ethanol or methanol at 70% or higher), P (*p*-Phenylenediamine), and I (Lugols iodine) to your repertoire.
- **UV lamp:** Centered on 350 nm (see below).



Spot test gear.

Spot tests often need to be applied to both the cortex and the medulla of the lichen, and often in a specific order, so make sure the capillary tubes are specific to only one chemical. I accomplish this by making my K tube longer than my C tube since KOH is more commonly called for in most ID keys. To limit having the toxic P test rolling around, I make the P tube so long that it rests in the P mixing container.

A UV lamp is also important for identifying lichens in tropical or subtropical areas, less so in temperate areas. Tropical lichens often contain xanthones, subtle yellowish pigments that fluoresce under UV light. UV lamps are also useful for other groups of lichens, including *Cladonia* and *Parmotrema*. The lamp must emit UV with a wavelength of around 350 nm in order for most UV+ substances to fluoresce. Cheap UV LED flashlights do not work! Some experimentation may be required to find a suitable lamp.[16] To conduct a UV spot test, simply go into a dark closet or cut holes out of a cardboard box for your eyes and hands, and turn on the UV lamp, being careful not to damage your eyes. If the lichen cortex has xanthones, it will fluoresce as a dull to bright orange or yellow color. If the lichen contains alectoronic acid or other subtler medullary chemicals, you will need to first flake off some of the cortex to expose the medulla before conducting the UV test. Alectoronic acid and other medullary chemicals turn a subtle to bright white or "ice blue" under UV, depending on the concentration of the chemical. This can be a confusing spot test if the results are not obvious; just know that a dull or vibrant purple color indicates a negative UV reaction.

My preferred capillary tubes are made by Fisher Scientific (70 µL, product number 22-260-943). You can get 100 for ten dollars. Before you use one, first create a narrow application point by holding the middle of the glass capillary tube over a small flame until the glass is soft. Then pull from opposite ends to break the tube at the center. Using sand paper or a rough surface, gently rub the narrow tip until there is a small hole. The capillary tube will pull chemicals up inside using capillary force and will pour them onto the lichen when the tip touches the thallus.

Lichen Chemistry

		Color	K	C	KC	UV	P	Group	Examples	Notes
Yellow, Orange, and Red Pigments	Parietin	Orange/red	Wine-red			Orange-ish		A	*Caloplaca, Teloschistes, Xanthoria*	Highly variable according to sun exposure.
	Calycin	Yellow	Faint reddish		Faint reddish	Pale orange		PA	*Candelaria*	Pulvinic acid derivatives are typically a purer, brighter yellow than any type of anthraquinone. Some *Candelariella* are orangeish. Beware pale *Xanthoria* and *Caloplaca* species in deep caves.
	Rhizocarpic Acid	Yellow				Bright orange		PA	*Rhizocarpon geographicum* group	
	Pinastric Acid	Yellow						PA	*Vulpicida*	
	Vulpinic Acid	Yellow						PA	*Vulpicida, Letharia*	
	Pulvinic Acid	Yellow						PA	*Pseudocyphellaria aurata*	
	Secalonic Acid	±Yellowishh	Yellowish	±Yellow-ish	Yellow-orange	±Yellow		A	Some *Myelochroa, Physconia*	
	Thiophaninic Acid	±Yellowish		±Yellow-orange	Yellow-orange	Bright orange		X	Some *Pertusaria*	Xanthones are most common in tropical species.
	Coronaton	±Yellowish				±Pink-orange		X	Some *Pertusaria*	
Other Pigments	Usnic Acid	Yellow-green			Gold			Df	*Usnea, Flavoparmelia*	Highly variable from yellowish to milky greenish; absorbs UV, resulting paradoxically in an extremely useful UV+ dull yellow for some cheap, broad-spectrum UV lamps.
	Atranorin	Pale gray	Pale yellow				Pale yellow	βOD	*Physcia, Parmelia*	With bluish tinge if in high concentrations.
	Lichexanthone	Pale gray?				Bright yellow		X	Some *Pertusaria, Pyxine, Ochrolechia*	Commonly found as a replacement for atranorin in cortex of tropical species.
	Melanins	Dark brown							*Melanelia, Cetraria*	Mostly northern and alpine.
	Fumarprotocetraric Acid	Brownish	Dingy brownish		±Pinkish		Orange-red	βODo	Cortex of many *Cladonia*	Turns brownish in sun.
C and/or KC Positive	Strepsilin			Blue-green	Blue-green			Df	*Cladonia strepsilis*	Related to usnic acid.
	Alectorialic Acid		±Yellow-ish	±Reddish	Red	White	Yellow-orange	βODE	*Gowardia nigricans*	
	Barbatic Acid Complex			±Orange-ish	Yellow-orange	White		βOD	Some *Cladonia*	
	Olivetoric Acid			Dark red	Dark red	White		OD	*Cetrelia olivetorum, Tuckermannopsis ciliaris*	
	Erythrin			Dark red	Dark red	White?		OD	*Roccella*	
	Lecanoric Acid			Dark red	Dark red			OD	*Flavopunctelia, Melanelixia, Pseudevernia*	
	Gyrophoric Acid			Fleeting pink	Rosy-red			OD	*Umbilicaria, Trapelia, Ochrolechia*	Typically weaker, more fleeting C+ than lecanoric acid, but both vary according to concentration; tiny needle-shaped crystals in water.
	Cryptochlorophaeic Acid		Slow reddish	±Purplish	Purplish	±White ish		OD	*Cladonia cryptochlorophaea*	
	Protocetraric Acid		±Yellow-ish		Rosy-pink		Orange-red	βODo	*Flavoparmelia*, some *Hypogymnia*	

Lichen Chemistry		Color	K	C	KC	UV	P	Group	Examples	Notes
C and/or KC positive	Physodic Acid				Rosy-pink	±Whit-ish		ODo	Many *Hypogymnia*	
	Alectoronic Acid				Pink-violet	Whitish		ODo	*Alectoria sarmentosa*	
	Lobaric Acid				Pink-violet	White		ODo	Many *Stereocaulon*	
	Divaricatic Acid				±Pink-violet	White		OD	*Some Canoparmelia, Dirinaria, Evernia*	
	Perlatolic Acid				±Pink-violet	White		OD	*Canoparmelia caroliniana, Icmadophila*	
K and/or P positive	Psoromic Acid					White?	Yellow-orange	βODo	Some *Cladonia, R. geographicum* group	
	Thamnolic Acid		Deep yellow				Yellow-orange	βOD	*Imshaugia, Thamnolia,* some *Cladonia*	K and P usually much stronger and quicker than atranorin.
	Norstictic Acid		Yellow-> red				Yellow-orange	βODo	Many *Usnea, Xanthoparmelia*	Produces distinctive red needle-shaped crystals in K.
	Salazinic Acid		Yellow-> red				Yellow-orange	βODo	Many *Parmelia, Xanthoparmelia*	Typically K turns darker and less bright than norstictic.
	Stictic Acid Complex		Yellow-> orange				Orange	βODo	Some *Lobaria, Pseudocyphellaria*	K varies from yellow to almost red, but P is distinctly orange with less of the yellow intermediate stage of norstictic and salazinic acids.
	Galbinic Acid		Yellow-> orange				Orange	βODo	Some *Myelochroa, Usnea*	Usually mixed with other acids making it hard to detect.
	Pannarin						Orange	βODo	*Pannaria*	Produces distinctive red needle-shaped crystals in P.
	Physodalic Acid		±Brown-ish				Orange-red	βODo	Many *Hypogymnia*	
	Lividic Acid Complex		Pinkish-brown					ODo	*Hypotrachyna livida* and *H. pustulifera*	
Just UV positive	Evernic Acid					White		OD	*Evernia prunastri*	
	Sphaerophorin					White		OD	*Sphaerophorus, Haematomma*	
	Squamatic Acid					White		βOD	Some *Cladonia*	
	Diffractaic Acid					Whitish		βOD	*Usnea ceratina* and *U. trichodea*	CK+ bright yellow-orange, but rule out K+ first!
	Sekikaic Acid					Whitish		OD	*Dirinaria confusa, Ramalina montagnei*	
	Homosekikaic Acid					Whitish		OD	*Cladonia rei*	
	Stenosporic Acid					Whitish		OD	*Ramalina stenospora*	
All negative	Confluentic Acid							OD	*Lecidea tessellata*	Thin sections produce bubbles in K (use microscope!).
	Fatty Acids								*Cetraria, Kaernefeltia*	e.g. Aliphatic, caperatic and lichesterinic acids.
	Triterpenoids								*Nephroma, Peltigera*	e.g. Zeorin and eucotylin.

Secondary Chemicals Chart

OD – *Orcinol depsides*
ODo – *Orcinol depsidones*
βOD – *β-orcinol depsides*
βODo – *β-orcinol depsidones*
βODE – *β-orcinol dibenzylesters*
A – *Anthraquinones*
X – *Xanthones*
PA – *Pulvinic acid derivatives*
Df – *Dibenzofurans*

Compiled by Jason Hollinger.

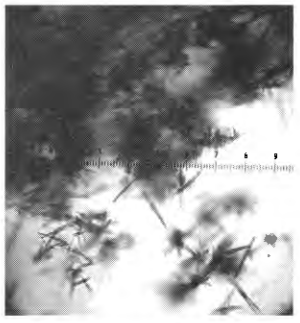
It can be hard to get only small quantities of these substances. If you're looking to get set up with just enough to get going, contact the webmasters at MushroomObserver.org or WaysofEnlichenment.net and they'll kindly set you up with everything a budding lichenologist might need.

DIY Chemical Spot Tests

- **C:** Fill a glass eye dropper bottle with regular chlorine bleach. C breaks down pretty quickly so change the C in your bottle every couple of months, and change your jug of C every six months or so. If it doesn't smell strongly like bleach, it's probably time to replace it.
- **I:** Easier to buy than make. Look for Lugols solution online.
- **K:** A bit trickier to make. Buy some reagent grade pellets of potassium hydroxide online from a science store. I use Fisher Scientific S71978. These pellets are 85% KOH, so you want to get it down to 10% KOH by adding 9 parts water to 1 part KOH pellet (e.g. 1.5 tablespoons water to 0.5 teaspoons KOH). Mix the ingredients in a glass container, put on the cap, wrap it in a cloth towel, and gently shake the container. Be careful, the reaction of water and KOH creates a lot of heat. Alternately, sodium hydroxide and ammonium hydroxide will work in a pinch. The former is sometimes available at supermarkets or hardware stores as Red Devil brand Drano™.
- **P:** Trickier still. P contains a chemical that is hard to get. P comes as little crystals, to which you add a couple drops of ***E*** (70% ethanol or methanol). The crystal(s) dissolve after a second, after which point they are taken up by a capillary tube. Take a chunk of the thallus, place it on a glass slide or piece of index paper to do the spot test, then throw out the thallus and carrier. Do not apply P directly to your specimen: over time it will turn your entire specimen black and bleed into the rest of your herbarium. Powerful stuff; use caution.

Lichen Microscopy

Macrolichens



Norstictic acid crystals from a Bryoria spp., *Southern Chile.*

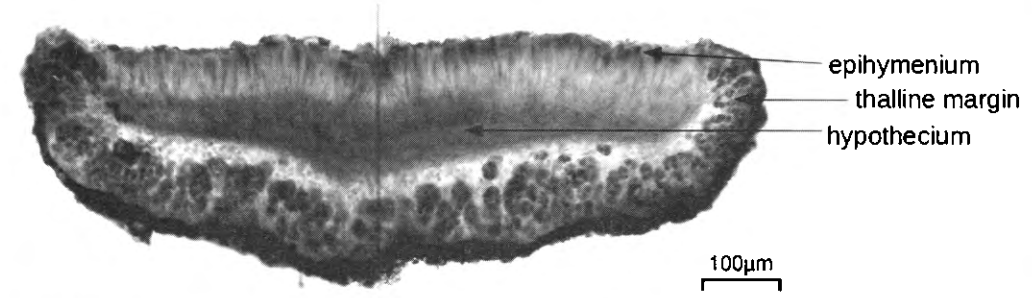
Compound microscopes are not necessary for identifying most macrolichens (non-crustose species). For these larger species, usually the only time you will need to use a microscope is to check for norstictic acid crystals. Norstictic acid is a relatively common lichen chemical; species with norstictic acid are scattered throughout most families and genera, so it's important to get comfortable with this test.

To test for norstictic acid, take a relatively thin section of the thallus, place it in a drop of water on a slide, put a cover slip on top, and press down with an eraser to squish the section. Then add a drop or two of K to one side of the cover slip, using a piece of tissue paper on the other side to wick up the extra water and pull the K across the slide. Look under the scope at 100x for a red hue forming around the thallus. At 400x you should slowly start to see linear-shaped red needles that form star shaped crystals. This is strikingly beautiful. If you see those crystals, you've got norstictic acid. If you don't get crystals then you probably have stictic or salazinic acid, both of which also react positively to K with a yellow to orange or red color.

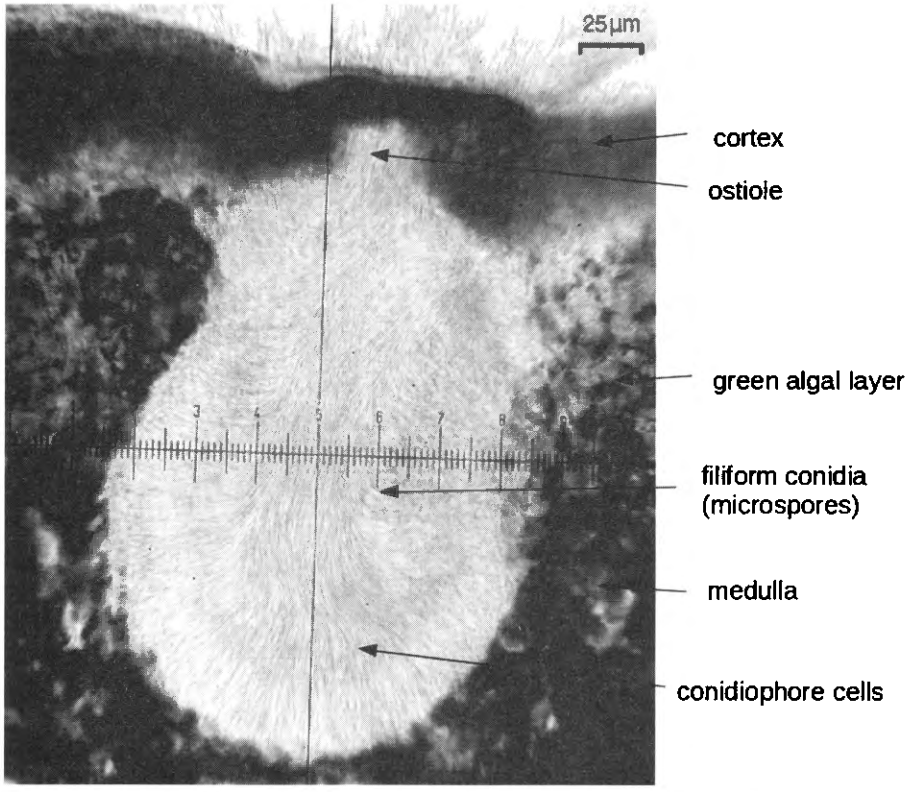
Crustose Lichens

To identify most crustose species you will need to use a compound microscope. Microscopy with lichens is nearly the same as microscopy with ascomycetous fungi. You generally do a vertical section through the apothecium, perithecium, or pycnidium using a razor blade and a dissecting scope at 10x or 20x. To prevent pieces from flying and to keep asci from shattering, wet the apothecium first. To get a really thin slice, try to cut little pie-shaped wedges, one side really thin, the other a little thicker. Getting thin sections that include all the important parts (i.e. the asci with spores still inside, the margin and exciple, the ostiole if it's a perithecia) can be challenging at first, but patience and practice helps—remember that even the best lichenologists had to learn this skill as well.

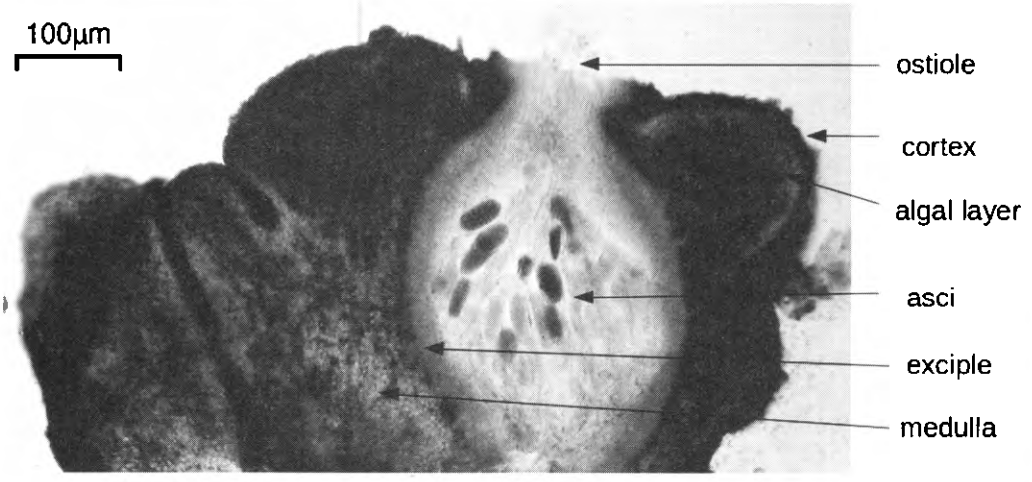
After slicing your sections (a few slices is enough), place a drop of water on the center of a glass slide. Then use a wetted tip of your razor blade to pull the section onto the blade (the power of hydrogen bonds!), carry the section to a glass slide, and then dip the tip of the blade into the drop of water so that the section is pulled onto the slide. Place a cover slip over the slide, and view it under



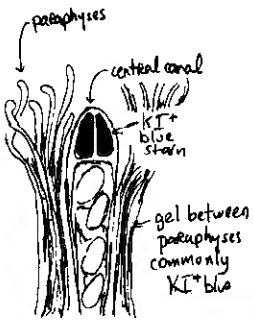
Apothecial section of cyanolichen Peccania subnigra. *Note the presence of the photobiont in the rim of the disc. The presence or absence of a thalline margin is a major classification in crustose lichens. Lecanorine apothecia have a thalline margin that is concolorous with the thallus. In contrast, lecideine apothecia lack photobionts in the apothecial rim and appear concolorous with the disc.*



Pycnidia of Rhizoplaca melanopthalma. *Note how tiny the condia (asexual microspores) are compared with the large muriform spores of the perithecia in the figure below.*



Perithecia of Staurothele aureolata. *Note the large muriform spores and the unusual presence of green algae amongst the asci, signatures for this species.*



Typical ascus stain for a Lecanora *species, notice the helmet shape of the KI+ stained ascus tip and the central canal that goes through the entire tip. This canal facilitates spore discharge.*

a compound scope at 100x and 400x. Larger power objectives are usually not necessary. If you are looking at an apothecium you'll want to note the presence or absence of algae in the margin. If you are observing a perithecium, look for the shape of the *ostiole* and *exciple*. Also note the number of spores per ascus (4, 8, or too many to count), the color of the spores (brown or colorless), as well as if the spores are broadly or narrowly ellipsoid, if they have any septae (cross walls), or if they have numerous jig-jag septae (known as *muriform spores*). In order to get an accurate spore size, you want to measure only mature spores. For this you will need to gently push some spores out of their asci. This can be done by pushing a soft pencil eraser on the cover slip, squishing the asci so that spores squeeze out. Lastly, note the color of the *epihymenium* (the thin and often colorful layer above the asci) and *hypothecium* (the tissue below the asci).

Chemical tests of ascomata sections are often required for crustose lichens. Luckily, they are not very difficult to do. The trick is to use a tiny piece of toilet paper to pull liquids from one side of the coverslip to the other—effectively washing the section in different chemicals—and then observing color changes to the ascomatal section. The most common chemical test is a KI test: potassium hydroxide followed by iodine. This test will reveal amyloid structures in your section. For lichen ascomata, first prepare your section as described above, then place a couple drops of KOH on one side of the cover slip, and place the piece of tissue paper on the other side. Under 100x you'll see cellular material move rapidly towards the tissue paper side as the tissue paper wicks up the water and pulls the KOH under the cover slip. Often, the tissue will only turn hyaline or pale brown in response to the KOH. A color change in the epihymenium to green, purple, or red is notable. Repeat this process using a couple drops of water to wash the KOH out of the asci, then repeat this process using a couple drops of I (Lugol's iodine). The iodine will change the water under the slide to a yellow-orange hue. If this does not happen, it may be because you didn't wash out the KOH sufficiently (KOH seems to repel iodine), so add a couple more drops of water to the side of the cover slip, and replace the tissue paper on the other side. If it's completely wet and not wicking anymore, try adding the iodine again. Usually part of the section will turn bright blue, and you'll be zooming in to look at the tips of the asci under 400x to see what parts turn dark blue.

In practice, this test can be exceptionally difficult to interpret at first. The hymenial gel of many species turns dark blue, completely obscuring the delicate reaction in the ascus tip. It is essential to gently separate the asci in order to see them clearly without mangling them beyond recognition. Even when done perfectly, it takes practice and experience to learn which asci are at the appropriate stage of development to display the desired internal structures. But when you finally get the hang of it, this ascus stain is an invaluable and essential character for identifying most groups of crustose lichens. One of its primary benefits is its ability to indicate the type of spore dispersal apparatus used, such as whether the asci are unitunicate or bitunicate.

Tips

As with other fungi, Mushroom Observer is a great website for getting help with identifying lichens. The Consortium of North American Lichen Herbaria (CNALH) is an online database that has range maps for species found around the world, although there is a bias towards North American species. The International Association of Lichenology's website also provides a few links to additional resources.

Currently, there are no lichen books that reflect global diversity. Existing books are regional at best. If you are in the Southern Hemisphere, there is an online copy of David Galloway's *Lichens of New Zealand* that should get you to genus at the very least. Similarly, in the Northern Hemisphere, the keys in the book *Lichens of North America* may also get you to genus. For regionally specific lists of species and photographs, visit the webpages of a national or university herbarium. Armenia and Ireland have impressive lichenology websites devoted to exploring lichens in their respective countries.[17] Many university herbaria throughout the world have databases that will give you range maps of particular species so that you can find what is common in your area. And looking for and collecting what is common is the best place to start!

Harvesting Ethics and Tips

Considering that the average lichen grows only one millimeter per year, harvesting lichens must be done with great care and awareness of the lichen life cycle. Unlike mushrooms, lichens do not have an underground body. What you see is the entire lichen, and what you collect is an entire lifetime. Most lichens require a dozen years or more to grow just a few centimeters. Slow growing, determined little fellas that they are—collect with respect!

If you are harvesting lichens for dyestuff or medicine, it is best to harvest specimens from a disturbed area such as a recent logging operation, or from wind fallen trees. Generally, the more recent the disturbance, the more potent the medicinal compounds will be in the lichen.

If you decide to harvest in an intact forest, do so very sparingly. The forest uses all the nutrients that are gathered from the air by the lichen and subsequently deposited into the soil when the lichen decays. If you are collecting lichens for biodiversity sampling, be sure to collect off trail and with care to the substrate that you are taking from. Taking huge chunks of lichens off of trees to obtain samples is strongly discouraged.

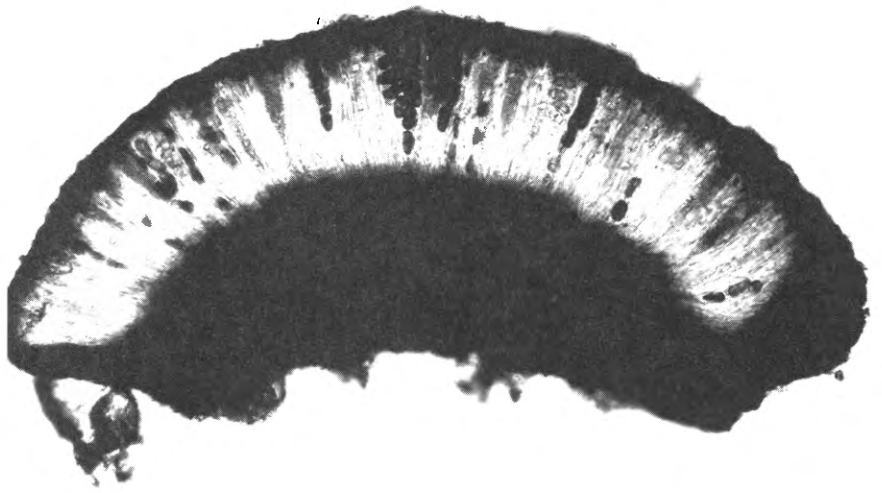
On your way out, give back to the forest by taking some of the beard lichens from a disturbed area and draping them over branches of the forests edge, thereby helping these elder lichens extend their reach. But most importantly, give thanks to the forest, to the tree you are collecting from, and to the dear lichen, whose life you hold in your hands.

Some lichen thalli have lived for over 1,000 years. Determining their age by their growth rate can also help determine the age of rock surfaces that they grow on. This discipline is known as lichenometry. Lichenometry has helped date the stones on Easter Island as well as approximate the time of ancient avalanches and earthquakes.

Lichen Herbaria

Whether you are an herbalist, lichen dyer, naturalist, or citizen scientist, creating a collection of the lichens you have obtained from the wild will help you stay organized while also helping preserve a local cultural memory of the species in your area. Herbaria are organized using similar methods to those described for mushrooms in Chapter 4. Simply air dry each lichen thoroughly and then place it into its own small envelope labeled with its species name, collection data, and identifying characteristics. To prevent mold growing on your specimens, herbaria should be kept below 50% relative humidity. It is also recommended to place specimens in a deep freezer for a few days to kill any insect eggs that are present on the thallus.

To easily track which collection corresponds to a given application (e.g. medicinal, ecological, or dyeing), it is best to number your collections starting with one and counting upwards for the rest of your life. If you'd like to bring your specimens back to the wild someday, just take them from their envelopes to a habitat that is similar to their original home and place them on their preferred substrate. Even if they've been sleeping in a paper packet for 100 years, in a few minutes after being exposed to humidity and light, they will come back to life.



The home lichen herbarium and lab of a much loved Canadian lichenologist.

Lichens and Humans

While lichens have played a helpful role in the development of many cultures around the world, their cultural significance amongst botanists and mycologists has largely been outshined by the intersection of humans with plants and mushrooms. Still, the small field of *ethnolichenology* holds a few fascinating insights into how lichens can assist in personal and societal resilience.

As Food

Lichens have been a part of diets from Asia to the Americas for thousands of years. Korean, Japanese, and Chinese cuisine highlights the flavor of *Umbilicaria esculenta* by using a cooking method that removes gyrophoric acid. The method involves boiling the lichen in a series of water baths, each at least an hour long, and avoiding breathing in the steam which contains the gyrophoric acid. There is even some evidence to suggest that the "manna," or "bread from heaven," spoken about in the Bible was actually the vagrant desert lichen *Aspicilia esculenta,* which today sustains herds of livestock in arid climates. Icelandic Moss (*Cetraria islandica*) has been used as a food source by aboriginal and Nordic people in the arctic areas of the Northern Hemisphere since the 9th century. Here, a porridge of the lichen is made by mixing its thalli with water or milk and boiled. It is said to be good if boiled for 10 minutes, bitter if boiled longer than 30 minutes, but sweet if boiled for 2–3 hours as the polysacchrides are released.[19] *Evernia prunastri* is similarly used to make bread or porridge in Turkey and Egypt.

As with mushrooms, it is important to be positive of your identification before eating any lichen. Lichens contain a vast range of chemicals, most of which have unknown biological effects. Many lichens can also absorb pollutants, such as heavy metals and radionucleotides.

Lichens are also used as a spice. *Parmotrema tinctorum* is used to flavor dishes in Saudi Arabia, Kuwait, and Oman, while *Parmelia abessinica* is used as a curry powder in India.[20] The beard lichen known as Wila to the first peoples of northwestern North America (*Bryoria fremontii*) has been used widely by different tribes as not only a food source, but also as a fiber for making fabric, and as a reliable source of tinder. Wila is traditionally baked at a medium heat with roots, meats, and berries for 12–24 hours in a covered pot placed in the oven or in the soil beneath a fire. For more information on lichens as food, and Wila in particular, check out the work and website of Stuart Crawford at the University of Victoria in Canada.[21]

Iwatake (Umbilicaria esculenta) *a delicacy in Japanese cuisine, on display at Japan's National Museum of Nature and Science, Tokyo.*

As Medicine

On the whole, lichens and their cultured mycobionts produce over 1,050 secondary metabolites (chemicals that are not necessary for the cellular functions of the individual bionts, but facilitate the emergent lichen symbiosis. Most of these chemicals are not found in plants or other fungi, and are exclusive to the lichen symbiosis). Medicinal uses of lichen chemicals range from menstrual teas to powerful antibiotics. Lichen-derived antifungal, anti-HIV, anti-microbial, and anticancer elixers have been a part of the pharmycopoeia of healers and health practitioners around the world for thousands of years.

The green beard lichens in the genus *Usnea* include some of the most widely used medicinal species, with recorded use reported from Traditional Chinese Medicine (ca. 500 CE), ancient Greek (Hippocrates, ca. 400 BCE), and traditional and modern Ayurvedic traditions. Bioscience research has demonstrated the powerful inhibitory effect of usnic acid against a variety of human pathogens including *Staphylococcus aureus, Bacillus subtilis, Klebsiella pneumoniae,* and *Mycobacterium tuberculosis.* Usnic acid has also been found to have powerful anticancer properties against leukemia, endometrial carcinoma, breast cancer, and pancreatic cancer. Tinctures and other herbal remedies utilizing usnic acid, as well as other chemicals, may require preprocessing of the *Usnea* lichen prior to use if a more potent formula is desired (e.g. heating). For more information on preparing lichens such as *Usnea* for medicinal purposes, see the booklet by herbalist Christopher Hobbs, *Usnea: The Herbal Antibiotic and Other Medicinal Lichens,*[22] as well as the review article by Moreno Cocchletto.[23] For more information on the use of lichens in folk medicine, check out Stuart Crawford's chapter "Lichens Used in Traditional Medicine" in the recent book *Lichen Secondary Metabolites.*[24]

Other powerful lichen chemicals include gyrophoric acid, divaricatic acid, barbatic acid, norstictic acid, and diffractaic acid. These chemicals, along with others including atranorin and parietin, demonstrate inhibitory and/or cytotoxic effects against many types of cancer including breast cancer, prostate cancer, and lung cancer. For further information about antibiotic, anticancer, and immune stimulating effects of lichen compounds, check out the research of lichenologist Gajendra Shrestha, particularly the article "Lichens: A Promising Source of Antibiotic and Anticancer Drugs" in *Phytochemistry Reviews.*[25]

Most lichen chemicals are very potent and biologically active and should be handled with care when used medicinally. Some studies have shown usnic acid to be damaging to the liver in high concentrations, and that the cytotoxic activities of some anti-cancer lichenic compounds may be damaging to benign cells. Be sure to do your research, and above all, correctly identify your lichen species. Similar species in the same genera often have vast differences in associated chemistry. For instance, Usnea *is a genus of over 300 species and most species contain various arrays of associated chemicals, not just usnic acid. While these additional chemicals may be beneficial medicines, it is important to know the chemical content to account for contra-indications and dosage.*

As a Dye Source

Lichens have been used as a dye source from the Incan peoples in Peru to the First Peoples in North America, Australia, New Zealand, India, Japan, and throughout Europe. Written accounts date back to the 3rd century CE. Thin layer chromatography has been used on ancient Norse fabrics to demonstrate that lichens were used as dyes in Scandanavia during the Bronze and Iron ages.[26] The dyes found in lichens require no mordants, and the pigments can be used both to dye fiber as well as to paint objects, hair, and skin. Many henna formulas contain lichens such as *Anaptychia ciliaris, Lobaria pulmonaria, Parmelia karatschadalis, Parmotrema chinense, P. perforatum,* and *Roccella fuciformis.*[27] For more information on working with lichens as dyes, see Appendix D.

Culturing Lichens in the Lab

The two primary strategies for culturing lichens are *in vitro* and *in situ*. Each practice has its own applications, strengths, and shortcomings. Folks doing restoration projects will be drawn to *in situ* culturing as the results are often much more successful when culturing in the lichen's original type of habitat.

In vitro cultivation is often used for taxonomic purposes in order to identify the photobiont or endo- or epilichenic bionts. On plates of agar, the lichen symbiosis usually disintegrates as the fungi and algae begin to grow separately. The separate growth of each biont is distinctly different than the original lichen, more akin to fuzzy mold and green algae growing next to each other than the intricate, charismatic form of a lichen. A primary benefit of separating bionts is that the photobiont is able to carry on its full life cycle and thus can be identified to species. Similarly, the epibiont bacteria and endolichenic fungi will also disassociate from the lichen, allowing for identification of these otherwise invisible bionts. This makes an intriguing venture for people interested in photobiont taxonomy, endolichenic fungi and bacteria, and the construction and dissolution of the lichen symbiosis.

In vitro cultivation uses agar plates that are specialized to a particular biont. Methods for aseptic fungal cultivation are covered in depth in Chapter 8. The following information covers techniques specific to lichens and their bionts.

Culturing Mycobionts

Spore Method[28]

Culturing mycobionts can be difficult because of the concurrence of bacteria, fungi, and other microbes that associate with the lichen symbiosis. The spore method limits the agar's exposure to anything other than mycobiont spores by placing agar in the lid of the petri dish and the spore bearing surface on the bottom of the dish. This works best with a lichen with visible apothecia and a low nutrient agar recipe, such as a 4% distilled water agar medium (4 grams of agar and enough distilled water to make a 100 milliter solution).

1. Obtain a fresh lichen thallus or thaw a frozen specimen (lichens can be stored in the freezer indefinitely).
2. Clean the thallus with running water then use a knife to remove the apothecia or perithecia. Soak these spore-bearing structures in distilled water for four hours.
3. Pour the agar into the top of the petri dish thick enough so that the spores only have to travel about 5–10 millimeters. Allow the agar to set.
4. Attach the apothecia/perithecia to the bottom of the petri dish using petroleum jelly. Make sure that the spore bearing surface is not covered in jelly.
5. Place the top of the dish over the bottom and wait about one day or more for spores to discharge onto the agar. Several different agar lids can be used with the same bottom dish to increase your chances of obtaining a sterile culture from that ascoma.
6. Place the inoculated agar medium on top of an empty sterile petri dish bottom and wrap the plate in Parafilm.

7. Place the plate in a humid, dark area at 59°F (15°C) to incubate and germinate the spores. This may only take one day.
8. Use an inverted microscope or a strong dissecting microscope with a lit up base to see if the spores have germinated. Once germinated, transfer the mycelium to a more nutrient-rich agar such as a Malt Yeast Extract Medium or Lilly and Barnett's Medium, though make sure your pH is between 5 and 6 for optimal growth.

Thallus Fragment Method[29]

Culturing thallus fragments can be more difficult than the spore method because of potential contamination by other unknown bionts. Culturing these unknown bionts is very fruitful and important research, just be sure you also figure out which fungus is the mycobiont so that it can be differentiated from the other fungal bionts. Isidia often harbor other fungi, so to isolate the mycobiont, culture the white cottony medulla.

1. Remove a thallus fragment from the interior of a clean lichen and place it on wet paper in humid, sterile conditions. Some researchers place the fragment in a test tube filled with a bit of distilled water. Store at 59°F (15°C) for a couple of weeks until a number of hyphae grow from the thallus.
2. Cut out a portion of the elongated hyphae and place it in a fresh culture medium of your choice. Nutrified media is fine.
3. Repeat step 2 with a number of elongated hyphae to ensure that you have the mycobiont and not some other fungal associate. The mycobiont is the most abundant fungal mass in the lichen, so it should appear in the majority of the plates while a smaller number of plates will contain other fungi.

Culturing Photobionts

To culture photobionts, they are first removed from the inside of a clean thallus and placed in an agar plate. Various media formulas are used to culture green algae culture, with Bold's Basal Medium being one of the most common recipes. To grow cyanobacterial photobionts, MDM media is recommended. For more information on culturing media, see the National Institute for Environmental Studies Microbial Culture Collection.[30]

1. Clean the lichen thallus with tap water and, using a razor blade, gently scrape off the outer cortex of the lichen and clean the tissue again.
2. Using a sterile razor blade, remove only the photobiont layer from the lichen's medulla as best you can and place it onto the media.
3. Incubate at 59–68°F (15–20°C) in low light conditions for a month. Direct sunlight is not recommended. Subculturing may be necessary to obtain a pure culture.

Culturing Epibionts and Endolichenic Fungi

Use the methods above for culturing photobionts or mycobionts. Contamination will undoubtedly occur, but this is an opportunity to examine the various other fungi and bacteria that associate in the lichen. Culturing endolichenic fungi can be incredibly fruitful. Over 640 endolichenic fungi have been found in the pelt lichen *Peltigera neopolydactyla*. This number of endolichenic fungi is not unusual, but the patience of the researcher is quite notable.

For more detailed information on culturing mycobionts and photobionts, see the research of Yoshikazu Yamamoto, particularly the article "Isolation and Culture of Lichen Photobionts and Mycobionts."[31]

In Situ Cultivation for Environmental Regeneration

Habitat restoration efforts are often so heavily focused on establishing plant and animal communities that the lichen component of an ecosystem tends to be entirely overlooked. Likewise, where habitats are threatened by human disturbance, the importance of lichens to those ecosystems is often missing from conservation dialogues. When lichens are left out of rehabilitation strategies, a systemic gap in nutrient acquisition and retention can develop, leading to a plateau or limitation in the success of a restoration project. Lichens play critical roles in healthy ecosystem functioning. As such, their integration into restoration efforts should be increased wherever possible.

Whether you want to help protect lichens or introduce them into habitat regeneration efforts, several simple methods can be utilized to intentionally cultivate lichen species in forest or desert ecosystems. Most of these methods are variations on techniques that have been used in research experiments but have not yet been applied outside of the academic arena. These techniques are presented below in hopes that they will be applied and elaborated upon by citizen scientists and Radical Lichenologists around the world.

Forest Lichens

One of the many outcomes of cutting down a forest is the loss of lichen communities. To help protect these lichens from such destruction, species in areas slated to be clearcut can be rescued and moved to a similar habitat. Just be sure that the host forest and recipient forests are located somewhat close to each other and share similar climate and flora. These considerations are important to maintain locally specific adaptations in the recipient forest.

To move tree-inhabiting lichens, remove a small piece of bark that contains a lichen fragment and place it in a piece of biodegradable gauze that you then adhere to the bark of a new tree using something that will allow the gauze to stay in place for at least a year (e.g. tree sap or pins). Alternately, take a couple of thalli and rub them on the bark of a recipient tree to spread fragments of the lichen across the bark surface. For lichens growing on the ground, such as *Peltigera* or *Cladonia* species, take a chunk of the substrate and place it in a similar location in the recipient area, noting whether the host surface was a rotting log, sandy soil, or humus.[32]

Rangeland Lichens

In overgrazed or post-fire rangelands, there is a tremendous need for immediate soil stabilization. Lichens and moss are essential for this process, and techniques are still being developed to best facilitate the recovery of these habitats via lichens.

Many methods create an inoculum by creating a liquid slurry of soil crusts collected from intact sites, distilled water, and various nutrients, then pouring the mix on soil at the recipient site.[33] The mixture should be poured on a soil that has a similar texture (fine soils will have the best results) and pH as the original site. To do a rough test of pH affinity, apply some diluted hydrochloric acid (HCl, sold in hardware stores as Muriatic acid). Put a drop of HCl on the host soil and observe the degree of effervescence. Is it non-effervescent (no bubbles), slightly effervescent (a couple of bubbles), or very effervescent (a ton of bubbles)? Be sure that your recipient site has a similar level of effervescence.

More research is needed on different types of slurry mediums. Some researchers have found composted sewage sludge slurry to be a very successful inoculant for biotic crusts.[34] However, there are major concerns about heavy metals and other chemical contaminants that are often associated with sewage slurries and the safety of spreading it over our landscapes.

Yogurt, used to culture moss, may provide nutrition and assist in the adhesion of biotic crust fragments to soil particles. A bit of compost tea (discussed in Chapter 9) mixed with distilled water and applied frequently to the inoculation site (once a day at dawn or dusk) may increase the growth of early succession species. The first species to establish will be green algae and cyanobacteria, which are nearly invisible. To tell if your culture is successful at the early stages, the soil particles

will clearly begin to aggregate together and if you pick up a piece of the soil (a *ped*) and break it apart you will see clear dangling filaments. As time passes and the conditions become right, the site should grow darker as the cyanobacteria increase in bulk mass. Several months to, usually, over a year later, lichens will begin to establish. If a watering system is employed, a drip watering system is recommended over a mist system.[35]

Biocrust restoration desperately needs further investigation. Climate change and disturbance are shifting arid ecosystems into depauperate versions of their former states. Bare ground is increasing in many ecosystems that were previously grass-dominated. The Dust Bowl catastrophe that tore topsoil from over 400,000 square kilometers in central North America may repeat itself in arid regions such as the Great Basin Desert.[36] Unfortunately, there is a deep lack of creative biocrust restoration methods that require minimal infrastructure and can be applied on a broad scale. There simply aren't enough people thinking about and experimenting with biocrust remediation, and there are an incredible number of unknowns—not just unknown answers, but unknown questions, which is exciting but also daunting. For more information, check out the work of Matthew Bowker at the University of Northern Arizona, especially his article, "Biological Soil Crust Rehabilitation in Theory and Practice: An Underexploited Opportunity."[37]

Biotic soil crusts create a pinnacles-and-valley topography that captures rainwater, creates microclimates for microfauna, and holds the soil together, preventing wind or water erosion.

Citizen Science

Lichens are incredibly sensitive to changes in their environment, a fact that provides humans with a low-cost means for measuring the health and vitality of an ecosystem. Lichen diversity and distribution can be directly correlated to air quality and habitat disturbance patterns. This simple practice was first conducted by British schoolchildren in the 1970s. Known as "The Mucky Air Map of Britain," this pioneering project created a lichen distribution map based on collections from schoolchildren around Britain that clearly demonstrated a low diversity of lichens in areas of highly polluted air, as well as a surprisingly low diversity in remote areas downwind of industrial sites.

Monitoring Air Pollution

Compared with the cost of deploying air quality canisters (>$10,000), working with lichens as air quality biomonitors is an inexpensive and effective means for citizen scientists to understand the long-term effects of industries on an environment. There are three primary ways to monitor lichens for air pollution: 1) monitoring reduction in diversity and abundance, 2) monitoring morphological changes of individual thalli, and 3) measuring the amount of pollutants in the thallus over a period of time. Methods for measuring a reduction in diversity and abundance vary from study to study. Below are a few methods that have been modified from various sources.[38]

Percent Cover Method

This accessible method requires limited knowledge of lichen species. Punch 50–100 holes across a stiff piece of paper, equally spaced about 1 centimeter or more apart. The exact measurements are not critical, just be sure they are repeatable and standardized across the sheet. This sheet is now your "quadrat." Make a photocopy of it and save it.

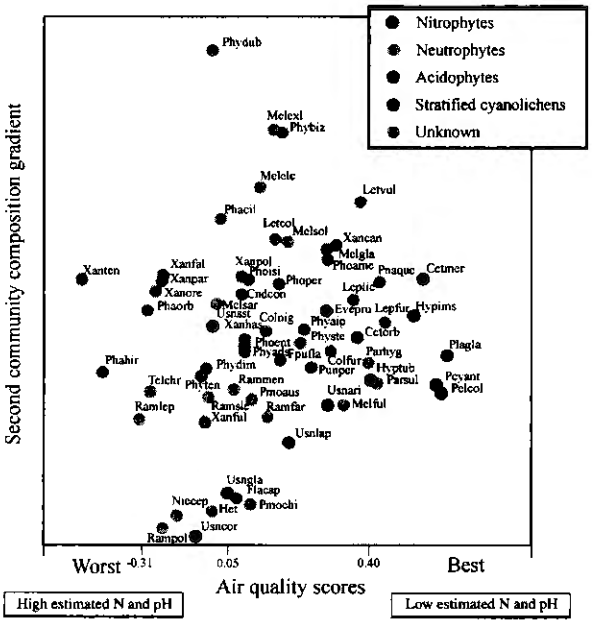
Pick a handful of trees that you'd like to sample. Put some sort of mark on each tree so that you can return to them later. You will need to be able to put the quadrat in the exact same location each time. It might be advisable to use a piece of degradable twine or stretchable cloth with a knot in the middle; the knot can be used to mark the location for the upper left corner of your quadrat. Other methods might be better. Do what works best for you. If you'd like to monitor lichens on rocks instead of trees, that's fine too, though epiphytes are usually more sensitive to pollution.

Take your paper quadrat and hold it over the surface of the substrate. Mark how many of the holes have lichens covering at least 50% of the surface beneath it. Divide that number by the total number of dots and multiply by 100. This gives you a "percent cover" estimate for that tree. You can also mark what percentage is covered by particular color groups (gray/blue, white, orange, green/yellow, brown/black). This may suggest the nitrophilic (tending toward orange) nature and general diversity of the assemblage. Ideally, the study would be repeated every three to six months or, at the least, after a few years.

In addition, you can also increase your sample size to 20+ trees in a polluted area and then survey the same number of trees in a non-polluted area. Increasing the number of plots you record at a site will increase the statistical significance and reliability of your estimates. Keep in mind that lichen cover may be different based on different types of trees, the height above the ground, and aspects (north facing versus south facing slope). Sunlight (i.e. percentage of canopy cover) may also have an impact on lichen cover. These factors can influence your results, so try to either keep these variables constant, or try to sample enough trees in different locations so that these variations can average out. Be sure to keep good notes!

Once the data is collected it should be processed using biodiversity statistics software. The best program is EstimateS, which is free and open-source.[39] There are also excellent and free biodiversity training lectures provided online by Biodiversity Informatics[40] that will give you an understanding of the different biodiversity indices used in EstimateS and how to evaluate the results.

Although numbers are powerful, they are essentially inert until they are brought to the attention of regional legislators and community action groups. Community organizing concerning industrial pollution and resource extraction often requires real life, measurable examples of impacts to be most effective. Thankfully, lichens give earlier responses, with more provable causal associations, than human impacts, such as health deterioration. But like most areas of lichenology, their interpretation as bioindicators has been underused and underexplored as a tool for community mobilization and action.



Air quality bioindicator species, as found along an air quality gradient

Species are listed as codes: the first three letters of the genera followed by the first three letters of the species, i.e. Bryfre is Bryoria fremontii. *Note that the occurrence of acidophyte genera in clean air locations is odd. The authors note that neutrophytes and acidophyte genera were classified based upon European indices and that species in these groups may need to be reclassified for North America. Table is from a publication of the U.S. Forest Service's lichen monitoring program.*[41]

Morphology Method

Lichens often show morphological distress in response to pollution, and photographs of these changes have the power to demonstrate the impacts of various pollution streams (e.g. coal power-plants, smelters, and vehicle exhaust) on the health of nearby communities and ecosystems.

To photographically measure morphological changes due to a new source of pollution, choose a couple sensitive and very showy species that are growing on trees or rocks near the new pollution source. Use a lichen pollution index[42] to find out which species in your area are sensitive to air pollution. Then take pictures of those lichens every month (if possible), starting before the pollution source is active, and then continuing to photo document the same lichen every month afterwards. Creating a cardboard frame that can be placed around the area being photographed may help with consistency and analysis of the photos later on.

Indicators of morphological distress due to pollution include curling up or bunching up very irregularly, turning white from the degradation of the chlorophyll, and crisping to a yellowish or brown color as the lichen dies.

If the pollution source is already in place, you can do a transplant experiment and then document morphological distress. Simply remove some pollution-sensitive lichens from the bark of a tree in a clean air area, attach it to the bark of the same type of tree in a dirty air area, and then document its morphological change over time. To increase the robustness of your study, set up a control so that you can be sure it wasn't the transplanting that caused deterioration of the lichen. For the control, transplant the same lichen species to a nearby tree in the clean air area, and then take photographs of it periodically as well. If the polluted air transplant shows greater morphological distress than the controlled transplant, then you've got a strong case for demonstrating the ecological impact of the pollution source in a tangible, visible way.

Dry-Weight Analysis

This method is used by state and federal agencies around the world as it gives quantifiable evidence for the amount of heavy metals, acid rain, and other pollutants in the air. If you are requesting air pollution canisters or resin accumulators to be placed in your community but the authorities are not providing you with funding, this method has the potential to give you hard, quantifiable evidence for authoritative action. The method involves using a mass spectrometer or similar device, which are rather common in most university chemistry departments. Depending on the pollutant being tested, mass spectrometry tests should be relatively inexpensive and easy to perform with a few days of training, if your local university will grant you access. If they won't, most graduate level chemistry students are trained in the basic procedure and analysis and might do it for a good cause. In either case, collect the lichens from upwind and downwind of the pollution source. The more sites you collect from along this transect, the more robust your dataset will be. After gently cleaning and drying the specimens, test for the suspected pollutants. Heavy metals such as lead and cadmium are among the easiest to test for. Gasses such as sulfur dioxide and radioactive isotopes are much more difficult to measure.

For comprehensive information on the particular pollutants that can be biomonitored by lichens, read the article by Marcelo Enrique Conti, "Biological Monitoring: Lichens as Bioindicators of Air Pollution Assessment—A Review."[43]

Monitoring Ecosystem Health

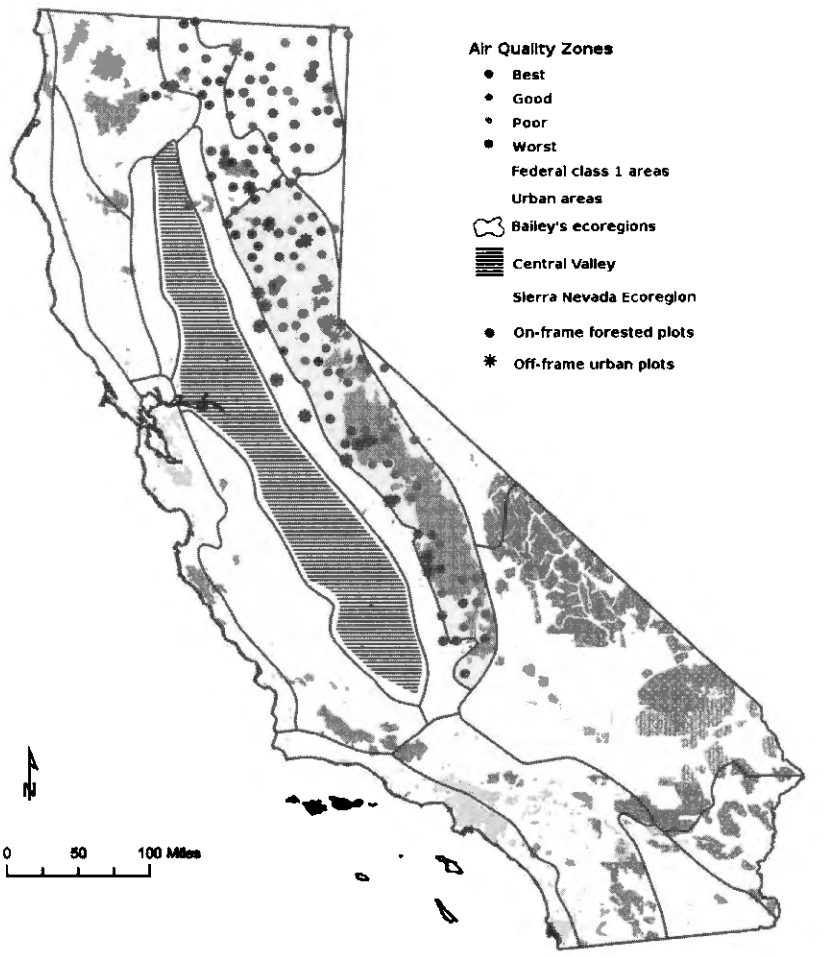
Conducting a biodiversity survey can tell you a lot about the quality and health of an ecosystem, from its air quality, to the continuity of habitat (old forest versus ancient forest), to its biodiversity. A total inventory is ideal in conjunction with plot-based methods for statistical rigor, but less intensive types of inventories and surveys can be conducted to assess an ecosystem.

A total inventory involves documenting all species present on all substrates within all habitat types in a given area. Often the habitat type is a vascular vegetation alliance or landform (i.e. mid-elevation canyon), which has many microhabitats within it (e.g. limestone outcrop, riparian granite boulders, riparian hardwoods, and upland shrub community). It is ideal to collect a voucher

specimen of every species found at each site, noting microhabitat and substrate for each voucher. Stratify these collection areas so that regions with different climatic variables (e.g. elevation, aspect, protection from wind), vegetation, and geology are visited.

Depending on time or experience limitations, various plot-based methods can be used to limit your survey areas to a particular size (lichen surveys conducted by the United States Forest Service are a 120-foot diameter circle plot), a particular group of lichens (e.g. epiphytic macrolichens), or target only bioindicator species. Excellent citizen science methods have also been developed for morphotype identification in place of species identification.[44] Many countries have indices for old growth forests or undisturbed arid land soil crusts. Although many of these are crustose lichens that take a bit of extra time to ID, targeting these species in your inventory can be very helpful in stressing the conservation value of particular areas.

For more information on rare lichens and their diminishing ecosystems, check out the Global Fungal Red List hosted by the International Union for the Conservation of Nature. For regional old growth lichen species indices for your region, do a search on www.scholar.google.com to find recent research in your area. Thus far, many ecosystems throughout the world have been assessed for valuable lichen bioindicator species, but much work remains to be done. For a general understanding of lichen bioindicators of forest health, see the work of Bruce McCune, particularly "Lichen Communities as Indicators of Forest Health."[46] For a general understanding of lichen bioindicators of rangeland health, check out the research of Jane Belnap and David Eldridge, especially their manuals on biotic crusts.[47]



Air Quality Bioindicators in California, USA

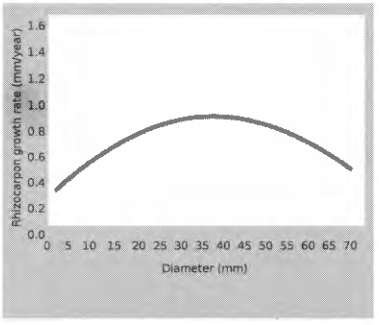
Lichen Communities are used by the U.S. Forest Service to monitor air quality along the Sierra Nevada mountains. Note how impoverished the lichen communities are in the Southern Sierra Mountains, presumably due to the nitrogen pollution coming from the Central Valley, one of the world's most productive agricultural regions. Figure adapted from a U.S. Forest Service research document.[45]

Lichenometry

Most species of rock crust lichens grow so slowly and regularly that they can be used to measure the age of rock surfaces. These might be unmarked tombstones, archaeological sites, or even moraines left behind after the retreat of a glacier. The most reliable time period is said to be between 50 and 1,000 years. Since radio carbon dating becomes inaccurate below 500 years and is limited to materials containing organic carbon, lichenometry can be a great tool in archeology and dating of rock surfaces.

The accuracy of lichenometry is based on the precision of calibration. To calibrate, find a rock surface that has had a surface exposed for a known amount of time. This might be a stone wall that has a commemorative plaque with the date, or a church that was built in a known year, or tombstone with a date on it. Ideally, the surface should be at least 20 years old. Then pick a crustose lichen that is common on that surface. The preferred species is the ubiquitous Map Lichen (species in the *Rhizocarpon geographicum* group), but other non-lobate crutose species should be fine as long as you calibrate. Note that lichens have a variable growth rate depending on climate and habitat, and little work has been done testing growth rates of other species, so although there are established growth rates of *R. geographicum*, it may or may not correspond with your region.

Once you've chosen your species, measure the diameter of the largest thallus in millimeters. Divide this by the number of years the stone has been in place to obtain an approximate annual growth rate. To refine the calibration, repeat it with several other rock surfaces that also have known ages. Be sure to note the rock type; granitic, basaltic/volcanic, and limestone/cement stone all have different nutritional profiles that will affect the growth rate and species composition. If possible, calibrate the annual growth rate using the same rock type as the rock surface being dated. These calibrations are location specific, and should be redefined in different bioregions, elevations, or habitat types. This consideration is not necessarily limiting, but rather opens up interesting possibilities of measuring how lichens respond to a changing climate or changing habitat.



Lichen growth rates are not necessarily linear. Rhizocarpon geographicum has been shown to have a curved growth rate. In Wales, when R. geographicum is about 17 years old it grows at a rate of 0.3 mm per year. When it is about 60 years old, it jumps to a rate of 0.9 mm per year and then decreases back down to growing at 0.5 mm per year when it is 100 years old. Graph adapted from Armstrong, 2004.[48]

Final Thoughts

"Lichens are *place*," says lichenologist Trevor Goward.[49] The meaning of this phrase twists around as it is considered. It is a koan that originates at the margins of lichenology, where philosophy blends with biological theory, and symbioses are recognized as keystones in the architecture of the biosphere. Place is philosophically conceived as the conceptual space where the subjective and objective overlap like colors in a kaleidoscope, where space and time intersect and reconnect, each changing the other. Similarly, lichens are where the concepts of the individual and the collective are seamlessly merged and dynamically changed by one another, and the distinctions between the two are nearly lost in complexity; where growth is no longer an aggregate building from DNA blueprints, but where growth builds from a dialogue of bionts, lichen, and ecosystem.

In lichens, we can find a biological analog for how to build healthy communities, gravitate towards a deeper understanding of the sacredness of relationships, and listen to the dangling murmur of emergent potentialities that can only become whole if we delve into relations the way that lichens do: fully dedicated to symbioses, fully present through all seasons of our experience, and always sharing the narratives of place.

Part III

Relation

Chapter Six

The Spores of Life

In P'eng-lai, The Island of the Blessed, the eight immortals of the Taoist pantheon esteem mushrooms in the center of their diet—an ingredient they attribute to their mastery of longevity. Throughout history, fungi have been revered for their unique qualities and today their flavors underlie the cuisines of nearly all of the world's cultures. Their addition to any meal is often a uniting factor—a buried flavor that makes people ask, "What is that?," but in a good way.

Some of the fungal flavors are so highly exalted that they have been set above most ingredients used in cooking, a quality only shared by such rare items as saffron or an extremely fine botrytized wine (itself a product of mold and yeast). The distinct musk of the aromatic *bis*-methylthiomethane produced by Italian White Truffles (*Tuber magnatum*) is one of the strongest examples of this fungal obsession. This single species is today the most expensive food in the world, in one case selling at auction for $231,840 per pound, six times the price of gold. Most of the fungal influences on the human diet are not as extreme or as visible—such is the nature of fungi. The most widespread role that fungi play in diet is through their role in the fermented foods of the world. These foods have not only helped the cultures of history survive countless famines and winters, but have also come to define the quality and form of central ingredients in many cultures due to the rich flavors these foods provide.

One of the primary flavors offered by the fifth major branch on the Mycelium of Life is umami, the fifth and subtlest taste sensation. After sweet, salty, bitter, and sour, umami is the sensation of a savory, brothy, rich, or meaty taste. It is what gives food a deep, satisfying, full-bodied flavor and mouthfeel—a result of the tongue's response to glutamate, an amino acid found in meat, cheese, nightshade plants, mushrooms, and many fungal ferments. All mushrooms are a rich source of umami, but the darker the mushroom is, the more umami it will express. The fungi are the richest non-animal source of this nourishing sensation. These savory factors, along with the medicinal qualities that an edible species provide, make fungi some of the most underrated foods in contemporary Western cuisine, a fact that is sure to change in coming decades.

Umami counterbalances saltiness, enabling recipes to reduce their salt content by up to 50% without compromising flavor. The word is derived from the Japanese umai, *"delicious."*

Megafood-Medicine of the Macro Fungi

Whether harvested from a nearby forest or cultivated at home, the fleshy fungi of the world stand as some of the healthiest whole foods that Nature provides. Though some species have been more researched than others, it seems that edible mushrooms are not only delicious, they are also highly nutritious and medicinal. For just as plants span the spectrum from food to medicine, so do mushrooms, albeit with an even narrower continuum. They are a food and medicine in one—a "functional food" or "megafood-medicine"—making them not only a tasty addition to any meal, but a healing pillar for any diet.

This dual nature of mushrooms was not overlooked historically. In China, the term *yakuzen*

Culturally important desert truffles include Delastria rosea, Kalaharituber pfeilii, Locolotuber gennadii, Picoa lefebvrei, P. juniperiand, Terfezia arenaria, T. boudieri, T. claveryi, T. leptoderma, Tirmania nivea, T. pinoyi, *and* Tuber oligiospermum.

has long been used to refer to dishes that incorporate medicinal mushrooms. In the Middle East, Mediterranean basin, North Africa, Australia, and Kalahari of Botswana, desert truffles in the genera *Eremiomyces, Kalaharituber, Terfezia,* and *Tirmania* have long been valued as an important and nearly sacred source of protein-rich food-medicine. The use of desert truffles has been documented in ancient Egyptian, Babylonian, Chinese, Japanese, Greek, Roman, Mesopotamian, and Islamic texts. In these cultures, truffles were (and still are) a valuable food source throughout the year, especially in times of drought.[1]

It is hard to pinpoint the most nutritious aspect of gourmet mushrooms, as most provide a significant portion of the vitamins and minerals that humans need. Some species, such as Chanterelles (*Cantharellus spp.*) can be quite high in carotenoids, the precursors to vitamin A. Most other edible species are high in the B complex of vitamins, including thiamine (B_1), riboflavin (B_2), niacin (B_3), pantothenic acid (B_5), and folic acid (B_9). The niacin content of some mushrooms can be on par with pork or beef, while the production of cyanocobalamin by fungi represents one of the only non-animal derived sources of this important precursor to B_{12}. Many mushrooms also contain high levels of vitamin C (as ascorbic acid) as well as ergosterol, a cholesterol-like compound that converts to vitamin D upon exposure to UV light. The vitamin D content of many mushrooms, such as Reishi and Shiitake, can even be intentionally increased by simply placing fresh or dried mushrooms in direct sunlight with their gills or pores facing up.

Mushrooms high in selenium include Amanita muscaria *(16.8–17.8 ppm),* Boletus edulis *(19.4 ppm), and* Agaricus campestris *(22.1 ppm).*

Mushrooms are also an excellent source of macronutrient minerals, such as calcium, magnesium, sodium, potassium, and phosphorus, as well as the microelements copper, iron, selenium, manganese, and zinc. A single serving of some mushrooms can even approach the daily requirements of iron and phosphorus. But, unlike mineral supplements that have varying degrees of bioavailability, the minerals in mushrooms are often found in an ionic form that is easy to assimilate. Mushrooms are one of the few organic sources of germanium, an element that has been shown to increase oxygen efficiency, increase resistance to diseases, and counteract the negative effects of pollutants. They are also one of the primary sources of selenium, a trace mineral that works with vitamin E to combat harmful free radicals through the production of antioxidants. Selenium has also been suggested to reduce the risk of cancer, cardiovascular disease, and to minimize the effects of HIV, rheumatoid arthritis, pancreatitis, and asthma. As discussed in Chapter 8, the mineral profile of mushroom substrates can be designed to help increase the concentration of certain nutrients, thereby creating mushrooms with targeted nutritional profiles to help offset mineral deficiencies.

Protein-wise, mushrooms contain around 3.5–4.0% protein when fresh and around 19–35% dried. Compare that rate to the following common foods:

Fresh		***Dry***
Apples: 0.3%	**Milk:** 2.9–3.3%	**Wheat:** 2.7%
Oranges: 1.0%	**Pork:** 9–16%	**Rice:** 7.3%
Onions: 1.4%	**Beef:** 12–20%	**Corn:** 9.4%
Cabbage: 1.4%	**Chicken:** 18–20%	**Soybeans:** 38.1%
	Fish: 18–20%	

However, a complete assessment of a food's protein content should not just account for total crude protein content, but also for the variation in the food's amino acids, which are the building blocks of proteins. Of the 22 standard amino acids, 9 are not produced in the human body and must be obtained from food. Mushrooms contain all of these "essential" amino acids. Mushrooms are even one of the highest natural sources of the essential amino acid lysine, which is generally low in most cereal crops.

If mushroom nutrition lacks anything, it is fat content. By dry weight, most mushrooms only contain 0.6–3.1% fats, of which 70% is unsaturated fatty acids. As high amounts of saturated fats are critical for the healthy functioning of cells, tissues, and organs,[2] no human diet should be primarily mushroom-based. Lastly, it is also notable that mushrooms do not produce excess free radicals anywhere in the body. In fact, mushrooms such as Chanterelles are radical scavengers, helping to remove damaging ions and heavy metals from the body.[3]

General Preparation Tips

In general, mushrooms should be cooked prior to consumption. Cooking not only kills off any potentially harmful microbes living on or within the mushroom, it more importantly breaks down the chitin-rich cell wall of the fungi, which humans are not able to digest. Arguably, eating raw mushrooms does not provide much in the way of nutritional or medicinal value as many of these benefits are locked up in the cell. Without thorough chewing, raw mushrooms pass through the digestive tract more or less intact, providing little more than dietary fiber to the consumer. Cooking mushrooms also significantly enhances their flavor and texture.

If you are working with wild mushrooms, it is best to thoroughly clean them at the time of harvest, thereby avoiding the introduction of dirt into the gills or other tight crevices during transport. At home, there will still be some dirt remaining. Try to avoid using water to clean this off. Mushrooms tend to absorb water like a sponge, diluting their flavor and harming their texture. Instead, simply clean off the dirt with a small brush, soft cloth, fingers, or the puff of your breath. When prepping boletes, some people remove the tube layer as it can be bitter in older mushrooms. Others keep it on and enjoy the taste.

If you need to store the mushrooms for several days, place them in a refrigerator inside of a paper bag or an inflated plastic bag. An uninflated plastic bag will suffocate the mushrooms, causing them to sweat and go bad. Truffles should be processed as soon as possible (discussed later) or stored in tightly sealed containers in the refrigerator. If left unsealed, their scent can seep in to most animal products, leaving you with truffle flavored eggs (yum!) or milk (yuck!). Below are several basic to foodie level mushroom recipes to get you started on munching the mushies. A wide array of other recipes can be found online and in most mushroom hunting books.

Precautions

Caution should always be applied when consuming a mushroom species that you have never eaten before. Allergic reactions to species that are normally considered safe are not unheard of. If you have a particularly sensitive stomach, only consume a small amount of one new mushroom species at a time and wait at least several hours or a day to see how your body reacts. Similarly, it is generally not advised for anyone to go on "mushroom binges" as several large, mushroom focused meals in a row can give some people GI distress and/or a lot of gas. Never eat an unidentified or semi-rotten mushroom or those harvested from a substrate that potentially carried heavy metals.

Basic Sauté

This simple recipe works for most fleshy mushrooms and is one that I prefer when highlighting a species in its own simple side dish. For soft mushrooms, tear the flesh into small pieces while a skillet warms up over medium heat. Tearing not only brings one into greater contact with the food, it also helps retain flavor in the mushroom's cells. For firm mushrooms, slicing is preferred. Once the pan is warm, throw in the pieces without any oil, stirring occasionally until water begins to cook out of the mushrooms. This helps the flavor concentrate in the mushrooms while also improving their texture. As soon as the mushrooms stop steaming, throw in a hefty helping of butter or oil and stir until the mushrooms are cooked to the consistency desired. I personally like mushrooms somewhere between chewy and crunchy, but other mycos I know like them soft and moist. Regardless, the dish isn't complete until a little salt and pepper is added, transforming the sauté into a simple, yet delicious smack in the mouth.

Bolete Bacon (a.k.a. King Bolete Rules With an Iron Skillet)

By Willoughby Arevalo

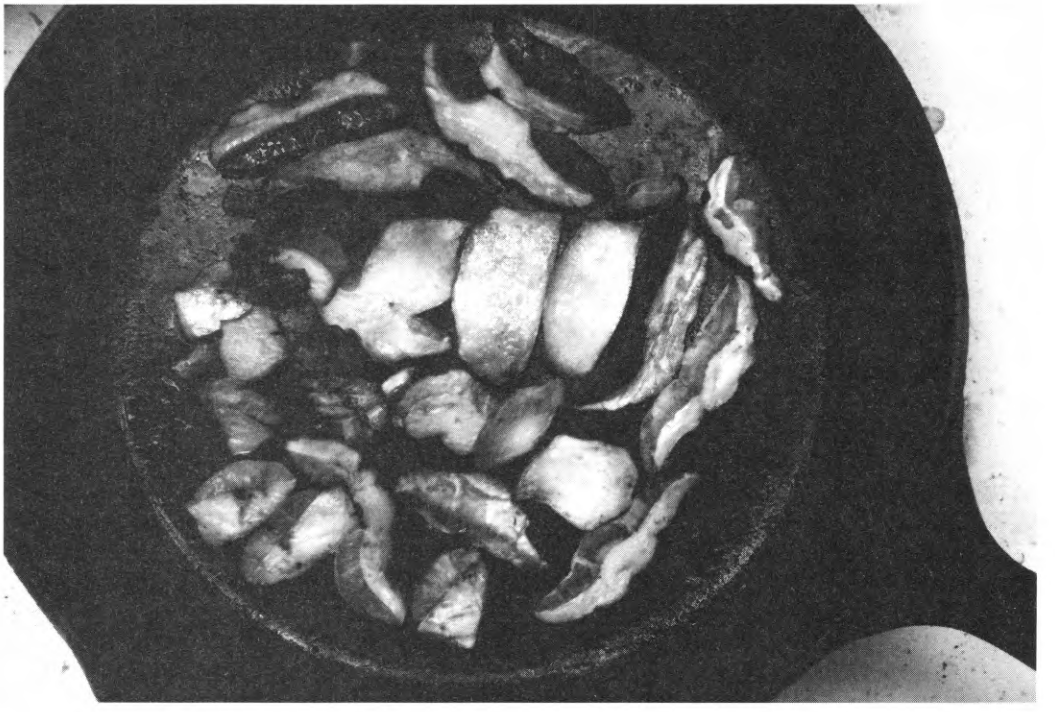
This is my favorite way to prepare boletes, such as Boletus edulis. *Prepared this way, even mature tubes will not become slimy. It also works well for dried boletes and many other mushrooms, especially Lobsters, King Stropharia, Shiitake, King Oyster, and* Agaricus *and* Russula *species. This simple recipe highlights the flavor of the mushroom and therefore is my preferred way to taste a new mushroom for the first time.*

Ingredients

- Mushrooms
- Butter, lard, or olive oil
- Salt
- Sugar (this is optional, but it actually boosts the umami flavor of boletes)

Process

1. Separate the caps from the stalks with a knife. Slice the caps and stalks vertically, resulting in long, thin strips that are about 3 millimeters thick.
2. If using dried boletes, rehydrate them for about five minutes in a minimal amount of cold water, then gently press out any excess moisture with your hands.
3. Warm a skillet over medium heat, and add enough fat to generously coat the bottom of the pan.
4. Arrange the sliced mushrooms in the pan so they cover the bottom but do not overlap.
5. Sprinkle some salt (and sugar) on them.
6. When side A becomes golden, flip each slice to side B using a fork.
7. When side B is done, transfer to a plate, and repeat until you have cooked all the mushrooms, adding more fat to the pan as needed. Be careful not to burn them, or they will become bitter.
8. Serve immediately, or incorporate into any dish you want.



If you want to make your dish a special ordeal, you can copy the ancient Romans by serving mushrooms in unique silver bowls, which they called boletaria.

Grain Spawn is Food-Medicine

The grain spawn produced as a part of mushroom cultivation (discussed in depth in Chapter 8) can and should be seen as a valuable, nutritious, and medicinal food source in its own right. Grain spawn is what forms the basis of most medicinal mushroom products. Compared to the labor and energy required to process grain spawn into medicines or cultivate whole fruit bodies, simply eating myceliated grains is an easy way to obtain much of the nutritional and medicinal value of fungi with little effort. The mycelium of most Oyster mushroom species tastes and smells sweet, while Lion's Mane mushrooms are so vigorous that they will often fruit directly on grains without any additional effort by the cultivator. When fungi are grown on glutinous grains, they can also significantly reduce the gluten content of the substrate, potentially reducing the inflammatory effect that this protein has on many people. This myco-enhanced, fermented food can be dried, at which point it remains a shelf stable and medicinal ingredient for skillets, soups, and, if milled, baked goods, smoothies, and salads.

Improving food products with mycelium can also be extended beyond grains. When grown on coffee beans and cacao nibs, medicinal mushrooms can eliminate the bitter flavor of these substances while infusing them with medicinal sugars. In effect, the mycelium smoothes and sweetens the flavor of the substrate, creating a tasty, healthy snack with a low glycemic index. These are just some of the many benefits of grain spawn, which can be easily and cheaply produced using liquid-based cultivation techniques.

Mushroom Katsup

Before tomatoes became the staple ingredient in ketchup, mushrooms were historically the primary component in this common condiment. If this hadn't changed, how would public perception of mushrooms be different today?

Ingredients

- 2 pounds (1 kg) mushrooms, drained, and trimmed
- 0.25-inch (0.6 cm) slice fresh ginger peeled, and minced
- 5 garlic cloves, minced
- 0.5 cups (250 mL) white distilled vinegar
- One 8-ounce (250 mL) can of tomato sauce
- 0.5 teaspoons ground allspice
- 0.5 teaspoons ground cloves
- 1 teaspoon sugar
- 1–1.5 teaspoons salt

Process

1. Purée the mushrooms, ginger, and garlic in small amounts in a blender or food processor until the mixture becomes paste-like.
2. Place the mix it in a heavy pot and add the remaining ingredients.
3. Simmer uncovered for one hour, stirring occasionally.
4. Pack the katsup into sterilized jars and process in a canner for 15 minutes. Makes about 1 quart (1 L).

Chanterelle Apple Pie

By Willoughby Arevalo

Sweet, savory, and unforgettable, the combination of apples, caramelized onions, honey, and Chanterelles is one of my favorite ways to highlight the fruity, spicy, and aromatic qualities of these autumnal mushrooms. This filling goes wonderfully in crepes, on toast, or with vanilla ice cream, but my favorite way to enjoy it is in a pastry.

Crust

- 2 cups (500 mL) unbleached white wheat pastry flour, alternately mix 50:50 with rye flour to make it a heartier, more savory pie
- 0.5 teaspoons salt
- 11 tablespoons cold butter, lard, or vegetable shortening
- Up to 6.5 cups (240 mL) ice water, optionally combined with a dash of Candy Cap mushroom extract

Filling

- 1–2 pounds (0.5–1 kg) fresh chanterelles, wiped clean and broken into chunks
- 1 medium yellow onion, sliced lengthwise
- Salt
- 1–2 pounds (0.5–1 kg) tart, crisp apples and/or crabapples, washed, cored, and sliced
- 1-inch (2 cm) fresh ginger rhizome, peeled and finely grated
- 2–4 tablespoons butter, lard (preferred), or coconut oil
- Sweet or hard cider
- 1 heaping tablespoon of honey

Process

1. Working quickly, grate the butter into the flour and salt.
2. Combine the ingredients with a fork.
3. Add the water little by little until the mix starts to clump together. Put down the fork and form a ball of dough with your hands. Do not overwork the dough or let it warm up: if you do, the pastry will not be flaky. Cut the ball in half and put it in the fridge while you make the filling.
4. Preheat the oven to 420°F (215°C).
5. If the Chanterelles are fresh, heat a large skillet over medium-high heat and dry sauté them until the moisture has evaporated. If they are relatively dry, skip this step.
6. Melt the fat in the skillet and sauté the Chanterelles and onion with a sprinkle of salt. If the mix is browning too fast, turn down the heat.
7. Continue until the onions are caramelized, deglazing the pan periodically with cider.
8. Add the ginger and apples and reduce the heat. Combine.
9. When the apples have just begun to soften (1–2 minutes), turn off the heat and add the honey. Mix in the honey well so it coats everything.
10. Adjust seasonings to taste.
11. Roll out half of the dough on a floured surface, spreading from the center outward (like mycelium).
12. When it has slightly overgrown your "pietri" dish, transfer it into the dish.
13. Roll out the other half of the dough, then fill the pie.
14. Cover with the second dough. Pinch around the edges to seal and cut some little vent holes in the top crust.
15. Pop it in the oven. After 10 minutes, reduce the heat to 360°F (180°C).
16. Bake for another 35–45 minutes, or until the crust is golden-brown and juice is bubbling up from the holes.
17. Cool at least 10 minutes before serving. Serve hot or cold.

Black Trumpet and Nettle Quiche

By Willoughby Arevalo

In Northern California, the seasons for Black Trumpets and nettles overlap as winter turns to spring. Trumpets can be difficult to find and are absent in some areas, but other spring mushrooms such as Oysters or Morels also pair wonderfully with nettles and make a great substitute. If you don't have time to make a quiche, an omelet with the same filling is nearly as good. Serves 4-6.

Ingredients

- 0.5 cups (125 ml) dark rye flour
- 0.5 cups (125 ml) unbleached pastry flour
- 1/3 cup (80 ml) cold butter
- 0.5 teaspoons salt
- Ice water
- 1 tablespoon butter
- 1 tablespoon olive oil
- About 1 pound (500 g) fresh or 2 ounces (60 g) dried Black Trumpets (rehydrated in a minimal amount of cold water), wiped clean and, if large, broken into pieces
- 2 shallots, 1 leek, or 1 onion, diced or sliced
- 2–3 cloves garlic or garlic scapes, minced
- 0.5 pounds (225 g) fresh nettle tops, washed, shaken dry, and chopped (you can include the stems)
- 1 parsnip or carrot, cut on the bias
- 1 cup (250 ml) of grated cheese (I like a combo of Jarlsberg, Gouda, and/or Cheddar, and maybe a small amount of Gorgonzola)
- 1–1.5 cups (250-375 ml) whole milk
- 3–4 eggs
- Salt and pepper
- Nutmeg or paprika

Process

1. Make the pastry as directed in *Chanterelle Apple Pie*, but since it's only a single crust, don't cut it in half.
2. Preheat the oven to 360°F (180°C).
3. Sauté the onions and mushrooms in the butter and olive oil over medium heat.
4. Add the parsnips or carrots once the onions become translucent.
5. Add garlic, mushroom soaking liquid (if using dried mushrooms), some salt and pepper at this time too.
6. When the roots begin to soften or when the onions have caramelized, add the nettles and cover without mixing them in. Turn the heat down a little bit.
7. When the steam condenses on the lid and runs back in, mix the nettles in and cook 2 more minutes, then let cool.
8. To make the custard, beat together the milk and eggs with some salt and pepper.
9. Roll out the dough and fit it into a medium-sized (no. 6) cast iron skillet or a high-walled pie dish.
10. Layer the cheese, then the mushrooms and nettles, then pour the custard over it all.
11. Dust the top with paprika or freshly grated nutmeg.
12. Bake 40–60 minutes or until the top is gently browned. Test doneness by sticking a butter knife in the center. If it comes out clean, the center is cooked.
13. Allow to cool and set up for 15 minutes before serving.
14. Excellent served with a salad of mixed greens that includes bitter, sour, nutty, pungent, and spicy types, and a glass of dry white wine or cider.

Fried Chicken of the Woods Sandwich

By Willoughby Arevalo

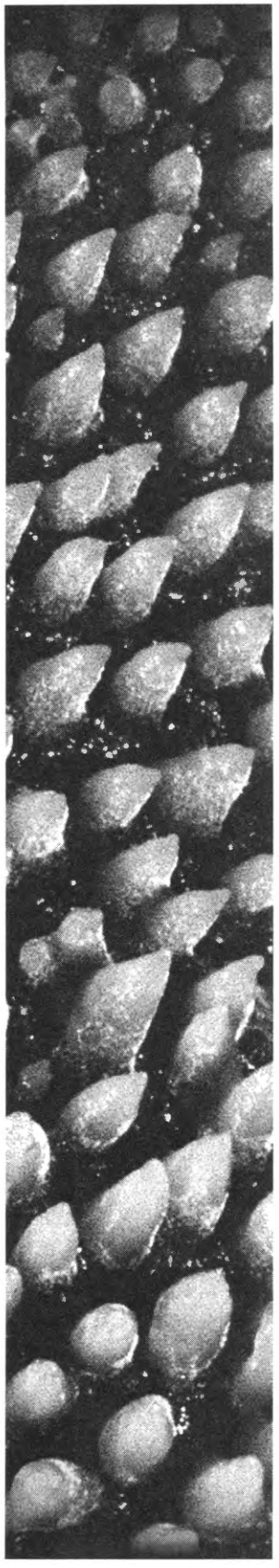
This mushroom doesn't really taste like chicken, but its texture is remarkably similar. You can substitute many of the following ingredients based on what you have in your pantry. My breading recipe is slightly different every time, and I never measure anything. Other mushrooms that go well this way include Shaggy Manes, Parasols, Agaricus *or* Stropharia *species, slices of* Sparassis *or Giant Puffballs, and big, mature caps of Oysters.*

Ingredients *(per sando)*:

- Flat pieces of Chicken of the Woods, enough to cover the bread
- A neutral, not overly bitter beer
- Salt and pepper
- Cayenne powder or hot sauce
- Flour
- 1 egg, beaten
- Sourdough starter (optional)
- Breadcrumbs, rolled oats, cornmeal, and/or nut meal (not more than two of these at a time)
- Spices such as toasted and ground coriander, paprika, or Cajun spice mix
- Oil for frying (I prefer ghee or lard)
- 2 slices of bread—your choice, but I prefer a crusty sourdough for this
- Pickled/fermented item(s) (e.g. cucumbers, sauerkraut, kimchi, peppers, or onions)
- Mustard
- Mayonnaise
- Cheese (e.g. sharp Cheddar)
- Greens (lettuce, arugula, mustard greens, sorrel, etc.)

Process

1. Marinate the "chicken" in some of the beer along with salt, pepper, and hot sauce for 20 minutes–12 hours. If the mushrooms are dry and tough, marinate them longer or simmer them in the marinade for 10 minutes. If you are not working with Chicken of the Woods, skip this step.
2. Make a 3-stage breading system in shallow bowls or plates, each with their own fork:
   - Seasoned flour.
   - Seasoned egg, with a splash of sourdough starter if you have it.
   - Seasoned breading (crumbs and/or meal. Flour works if your pantry is barren).
3. Drip-dry the mushrooms and coat in each stage of the breading on their way to the pan. Pat them off so you don't soil your oil with excess crumbs.
4. Pan-fry the breaded mushrooms in a healthy amount of hot fat, being careful not to burn them. Add more fat if the pan dries out before you're done.
5. After the flip, melt the cheese on top (optional).
6. Build your sando and grind! Wash it down with the rest of the beer. Give someone a high five.

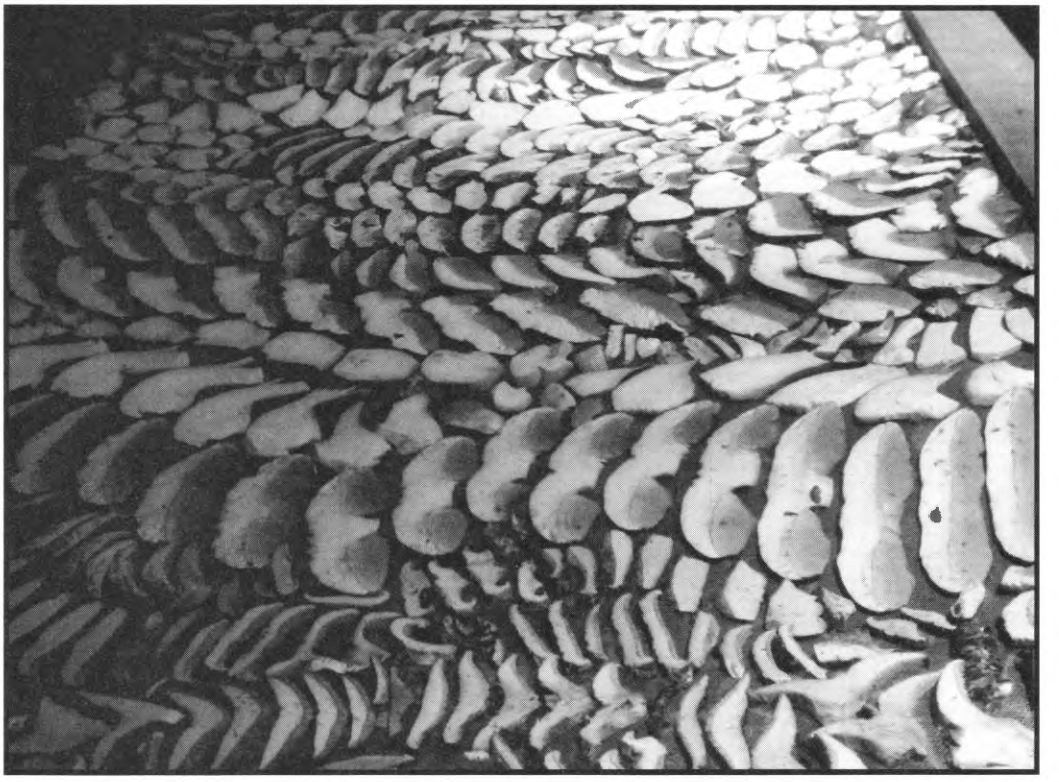


Preserving Mushrooms

Drying

When thoroughly dehydrated, denser mushrooms (e.g. Chanterelles, Morels, Shiitakes, and Boletes) can be stored for years in sealed jars. Drying can be done using the methods described for preserving collections in Chapter 4. For a particularly large harvest, consider powdering some mushrooms to make a seasoning or soup base. Powdering is also a great option for making use of tougher mushrooms like Chanterelles, Chicken of the Woods, or the stalks of Oysters and Shiitake.

To reconstitute dried mushrooms, simply soak them in a small amount of liquid. Hot liquid is absorbed fast, but robs some of the flavor. Cool water is better if you have the time. Any liquid works as the mushroom will act like a sponge, slowly expanding as it absorbs the liquid. Gravy works well here, as with most places. Be sure to save and use the soaking liquid as it will also be infused with yummy mushy goodness. Rehydrated mushrooms still need to be cooked to break down their cell walls.



Mushroom Seasoning

For rubs, veggies roasts, salad dressings, and sauces, mix the following ingredients and store in a sealed container. Makes about 2 cups (500 mL).

- 1.5 ounces (43 g) ground, dried mushrooms (*Boletus edulis* is an excellent choice)
- 1 cup (250 mL) Kosher salt
- 1.5 tablespoons red pepper flakes
- 1 tablespoon dried thyme
- 0.5 tablespoons freshly ground black pepper

Stock

Making a soup stock is a good way to capture the essence of damaged, tough, or short-lived mushrooms. The following recipe will keep for around five days in the fridge or about six months in the freezer.

Ingredients

- 2 pounds (1 kg) mixed mushrooms
- 1 onion, roughly chopped
- 2 carrots, roughly chopped
- 2 stalks of celery, chopped
- 2 crushed garlic cloves
- Some parsley
- Some thyme
- Salt and pepper

Process

1. Put all ingredients in a pot and add enough water to cover.
2. Bring to a boil and simmer for an hour and a half.
3. Strain into a jar, seal, and store.

Freezing

Most mushrooms can be stored frozen in well-sealed containers. However, it's best to first dry sauté them prior to freezing, otherwise the cells may rupture upon freezing, creating an unappetizing mess when they are later thawed.

Pickling

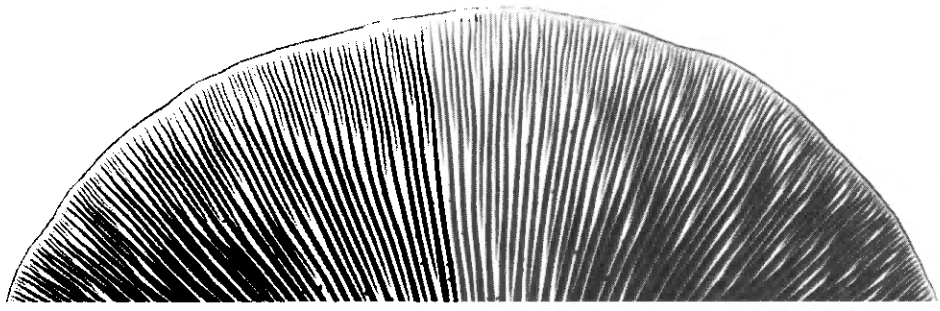
Firm-textured mushrooms are good candidates for pickling.

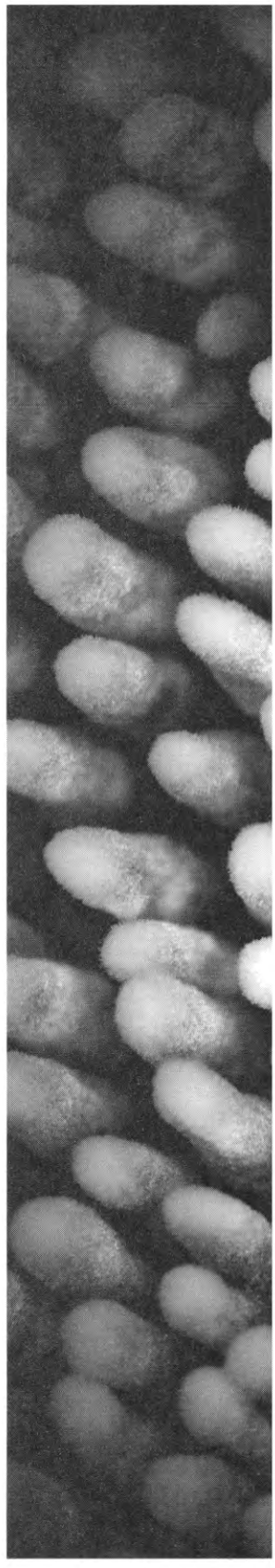
Ingredients

- 2 cups (500 mL) white vinegar
- 3 bay leaves
- 2 thinly sliced garlic cloves
- 0.5 cups (125 mL) balsamic vinegar
- 2 teaspoons peppercorns
- Some thyme or dill
- 1.5 pounds (0.7 kg) of mushrooms

Process

1. Simmer everything except the mushrooms for 15 minutes.
2. Add the mushrooms and simmer for 10 minutes.
3. Pour the mixture into a jar that has been boiled, seal the jar, and set it in a cupboard to pickle for a few days or weeks.





Lactofermenting

The fermentation of mushrooms with the aid of lactic acid forming bacteria (LABs) is a relatively uncommon form of fruit body preservation in Western culture, but not one without merit. LABs, such as *Leuconostoc mesenteroides*, are the microbes responsible for helping preserve vegetables and fruits in the form of sauerkraut, kimchi, sinki, kawal, and many other traditional ferments. They are in the air and on the surface of most foods all the time, but their effects are only seen when produce is submerged under liquid for an extended period of time. In such an anaerobic environment, LABs flourish and produce lactic acid, a compound that simultaneously discourages the growth of other microbes (including those that might be harmful) while also "pre-digesting" the submerged food. Further, these microbes are highly beneficial for the human digestive tract where they will often live once ingested and aid in the body's digestion processes.

Ingredients

- 1 pound (0.5 kg) mushrooms
- 3–5 crushed garlic cloves
- 0.5 teaspoons whey or (non-pasteurized) sauerkraut juice
- Fresh marjoram
- Fresh thyme
- Sea salt
- Water

Process

1. Slice the mushrooms into bite-sized pieces.
2. Tightly pack all of the ingredients into a 1 quart (1 L) mason jar.
3. Make a salt water solution to taste and cover the jar's contents, leaving an inch of headspace at the top.
4. Place a weight on top of the contents to keep it all submerged in the liquid.
5. Cover with a tight fitting cloth and set the jar in a 60–70°F (15–20°C) space, out of direct sunlight.
6. The mix will be slightly fermented in just a few days. However, the longer you wait, the richer the flavor will become. Some traditional vegetable ferments take months or years to fully mature.
7. Once the fermentation is deemed complete, remove the weight, seal the jar, and place it in the refrigerator.

Preserving Truffles

Soon after being harvested, the aromatic compounds in truffles quickly begin to volatize and dissipate. Thus, it is best to get fresh truffles directly into a preserving medium that will retain these compounds for an extended period. As these volatile compounds are fat-soluble, oils have traditionally been used to preserve truffles, but other ingredients work as well. Fruit bodies should be thinly sliced and the shavings placed into a clean, sealable container filled with salt, oil, wine, vinegar, or melted butter. If not frozen or canned, the flavor in these preserves can dissipate quickly, so try to eat them as soon as you can. As cooking truffles over even modest heat can burn off their delicate flavors, these infusions are best consumed as a fresh garnish.

Of Fermenting Fungi

For all of the incredible traits of the human body, our intestinal tracts are surprisingly not very well designed for the absorption of whole foods. Nor are we well equipped to even digest the food we eat. Though the enzymes found in human saliva and in the stomach assist in the initial breakdown of food, much of what is considered to be human digestion should actually be attributed to the diverse microflora of organisms that dwell within the intestinal tract. For just as the fungi and bacteria of the soil web reassemble nutrients into nourishment for plants and other organisms, so do the

gut microbes ferment, digest, and return the stuff that we consume into a simpler form—a protoplasm—that the intestinal lining can easily absorb. Every time we eat, millions of other organisms eat as well. In essence, the gut functions like a root turned inside and its inhabitants include many of the exact same species that predominate in healthy soil webs. Being of the Earth, the temple of the human biome reflects and contains this foundational ecology of the world. And as with any work that supports the habitats of Nature, so does the digestive flora require occasional inoculation and regeneration to maintain balance and ensure longevity in the human ecosystem.

Perhaps, then, this is why fermented foods have been revered throughout history by nearly all of the world's traditional cultures. As the product of molds, yeasts, and bacteria, fermented foods serve as a dense source (an inoculum) of gut flora. Ferments are a probiotic that replenish these beneficial microbes, which can be lost due to the consumption of antibiotic pharmaceuticals, antibiotic-infused animal products, or chlorinated water. When the stomach microbes are killed or their populations are shifted, an imbalance in the gut can arise, leading to an array of physical and mental health issues.[4] By consuming fermented food, we can help maintain a high level of beneficial microbes in our bodies and mitigate the impact of these environmental influences.

In addition, fermenting fungi and bacteria also act as pre-digesters that make the foods they grow on easier for our bodies to digest. They are sort of doing the work that our gut flora does, but before we eat. In effect, they speed up the time it takes for our food to be assimilated. This fermentation often enhances the quality of food, generally by increasing vitamin content, eliminating various plant acids that block nutrient absorption (e.g. phytic acid), and by enhancing or modifying the flavor of the food. Some of the most culturally important foods of the world are products of fermentation, including tea, coffee, chocolate, cheese, bread, alcoholic drinks, and cured meats. Fermented foods are not just a combination of their ingredients with a few microbes sprinkled on top; they are novel substances, the fusion of all the biology, enzymes, and substances involved. And just like every human culture, each fermented product is its own unique expression of this blending of elements and environment.

Most of the traditional ferments of the world hold unclear origins. With the ability to increase vitality and preserve foods for times of famine, ferments were often seen historically as gifts from the gods, victuals descended from the heavens to extend the lives of tribes and nations. Some, such as the mold-infused products of tempeh and koji, have unclear origins in their traditional cultures, while others, like many fermented drinks, have an unknown habitat outside of human societies. To create fermented foods is to tap into these rich traditions and to cherish the magic of microbial transmutation that has been woven throughout the history of human civilization. Across time and space, the fermenting fungi have offered any person or community a simple yet direct means to increase their health, resilience, and quality of life. To ally with these molds and yeasts is to uphold the human right for such self-reliance and, in a small way, to defy constrictions laid upon the sovereignty of the human body.

Making ferments is a great way to begin learning fungal cultivation. The concepts described below, as simple as they may seem, are a reflection of the more technical skills covered later in *Radical Mycology*. For all of these processes, the proper food for the organism is prepared, inoculated, and left to grow on its own until it is ready to harvest. But, unlike mushroom cultures that can be obtained through mushroom hunting, many of the fermenting fungi cannot be easily found. Thus, for most of the following recipes, you will need to find a source for the specific species and mixed cultures listed. Several commercial sources are listed in Appendix N, but be sure to ask around before ordering. A friend or community member might very well have extra cultures available that they would be happy to share. As these cultures grow, they replicate themselves, often resulting in an abundance that can and should be shared with other members in the community. Likewise, pure cultures of the molds required for some of the following ferments can be propagated, backed up, and shared using the same tools and techniques used for mushroom cultivation.

For anyone that is just learning to create ferments, it is important to recognize the difference between the tasty, tangy flavor of these foods and a failed project that has become overrun with spoilage. If any ferment becomes overrun by an unintended mold or begins to taste putrid, it should be composted and the project restarted. Also, it is important to avoid using plastic or metal mate-

rials when making or storing the following ferments as the microbes involved can corrode these materials, fouling your food. The fungally fermented foods listed here are just the tip of the probiotic iceberg. If you are interested in learning more iterations of the following themes, or if you wish to explore the world of bacteria-dominated ferments, I suggest reading Sandor Katz's excellent book *The Art of Fermentation*, which inspired much of this section.

Mycotonics

The beverages kombucha, kefir, and tibicos are some of the simplest fungal ferments and yet, also some of the most mysterious. Unlike the alcoholic drinks that are typically created by free floating, independent yeasts, these tonics are made by the coordinated actions of dozens of microorganisms that form a singular mass. Known as symbiotic communities of bacteria and yeast (SCOBYs), these mixed cultures have been used for millennia to transform teas, milks, and sweet liquids into bubbly, probiotic drinks that can be taken daily and easily made year-round. Appearing as rubbery discs or bumpy, gelatinous blobs, SCOBYs can seem strange at first glance, like something formed in the stomach of an animal or at the bottom of a pond. However, despite various attempts to discover the origin of these communities, the following SCOBYs have never been found independent from human influence and most SCOBYs have defied attempts by humans to artificially create them. In essence, SCOBYs are only produced by other SCOBYs. They are self-regenerative cultures that build off of each other like yeasts, conidiospores, or music scenes. And like an old growth rainforest, the SCOBY is a whole unto itself, an inseparable ecosystem with a sum much greater than that of its parts.

An interesting aspect of the lifecycle of SCOBYs is that though they can reproduce themselves, they are completely dependent upon the care of humans for their survival. If not fed regularly, SCOBYs can over acidify their environment to the point that they kill themselves. Thus, the relationship that we share with SCOBYs is akin to the mutual symbiosis of mycorrhizae or lichens where we, like the fungi, provide protection and support for the growth of the other in exchange for increased health. The benefits that SCOBYs offer are not minor. With such an array of microbes, the probiotic effects traditionally attributed to SCOBY drinks include boosting immunity, healing inflamed digestive tracts, fighting allergies, and reducing degenerative diseases. Not a bad trade for the labor it takes to make a pot of tea or pour some milk.

Kombucha

Easy to make and requiring little maintenance, the fermented tea drink known as kombucha offers one of the quickest routes toward allying with beneficial probiotics. Kombucha SCOBYs look like rubbery disks and typically contain one or more of the following yeasts: *Brettanomyces bruxellensis, Candida stellata, Saccharomyces cerevisiae, Schizosaccharomyces pombe, Torulaspora delbrueckii,* and/or *Zygosaccharomyces bailii*. Of the many bacterial species present, the alcohol fermenting species *Gluconacetobacter xylinus* is one of the most common.

Once you have secured a Kombucha SCOBY, all you need to do is make a pot of tea. Traditional recipes use the leaves of the tea plant (*Camellia sinensis*), however many people preferring to avoid the caffeine in this plant choose to break with tradition and use herbal teas instead. The tea can be made strong or weak and the amount of sweetener can be to taste, though 0.25 cups of sugar per quart of water is a good starting ratio. Most brewers use cane sugar, though alternative sweeteners can be experimented with, at the risk of potentially harming the SCOBY. Stevia is not a good option as it does not provide the carbohydrates the microbes need to grow.

Once the tea is brewed and cooled, pour it into a wide jar or bowl, mix in two teaspoons of kombucha liquid or vinegar, and add the SCOBY. The SCOBY will grow until it covers the surface of the liquid, so a wider container is preferred to increase the efficiency of the ferment. Cover the mix with a cloth, and place it out of the sun to ferment over the course of a few days or weeks. You know it's done when it tastes as tangy as you like it. If left long enough, kombucha can become lightly alcoholic (2% is approximately the highest a home brewer is likely to achieve). Despite some concerns over kombucha cultures becoming contaminated, there is no documented evidence of any kombucha-related poisonings due to pathogenic organisms.[5]

Tried and True Kombucha Brews

By herbalist and urban farmer Bonnie Rose Weaver

Nettle, Maté, and Mint
This trifecta has a lot going on. Nettles are known for their vitamins and trace minerals which give this blend a nutritive kick. Maté is a popular alternative to the tea plant, and Mint is a winning flavor. Together the tea is a tasty green standby.

Raspberry Leaf, Red Clover, and Oatstraw
Another high nutrient tea that makes a lightly floral flavor for kombucha. All three herbs are high in trace minerals and help with PMS, a tasty brew for everyday haus kombucha.

Black Tea
This is the traditional tea for making kombucha and makes a classic flavor every time. Try adding juice or fruit after the first fermentation for unique flavor combinations.

Rose Petals and Tulsi
Tulsi is also known as Holy Basil and is used in herbal medicine to relieve stress. Together with Rose this is a richly floral blend that will help you tap into your superpowers!

Kefir

Kefir is a tangy, yogurt-like drink, made from the fermented milk of cows, goats, sheep, or other animals. Unlike the pancake-shaped SCOBYs of kombucha, kefir cultures, or *grains*, are small and globular. They generally contain *Lactobacillus, Streptococcus,* and *Bifidobacterium* bacteria as well as yeasts that can digest lactose, such as *Kluyveromyces marxianus* and *K. lactis*. Other kefir yeasts may include *Kazachstania unispora, Saccharomyces cerevisiae,* and *Torulaspora delbrueckii*. One of the interesting things about kefir is that more than half of the microbes involved in the symbiosis are not named. Moreover, repeated efforts to create a kefir grain under controlled conditions have all been unsuccessful.

Kefir is made by pouring milk (ideally raw) over kefir grains inside of an acid-proof container (e.g. glass or ceramic). The grains should make up about 5% of the total volume. Cover the container with a cloth and place it out of direct sunlight at room temperature for several days. Agitate the mix once per day until the liquid becomes thickened and slightly sour, usually within a day or two. At this point, the grains can be strained out and used to make a fresh batch. Alternately, the kefir can be left out to continue fermenting, potentially to the point of obtaining an alcohol concentration of 3%! However, it is best to keep the grains moving to new milk frequently. If left for too long in the highly acidic milk they will likely die. Kefir grains can also ferment non-dairy liquids such as coconut milk or sweetened infusions, but the grains should be returned to milk at least once a week as they will weaken over time if not exposed to animal milk. Kefir can be consumed whole, salted and strained to make a type of cheese, used as a base for borscht, or serve as an LAB source for other ferments.

Tibicos / Tibi / Sea Rice / Aqua Gems / Water Kefir

Tibicos is a fermented, water-based drink made from small SCOBYs that are similar in appearance to kefir but do not require milk. These squishy little SCOBYs have been found in human cultures throughout the world and yet no two tibicos strains seem to host the same blend of microbes. Thus, each tibicos is said to produce a unique flavor profile. Some tibicos are considered ideal for certain drinks, such as the ginger plant, a tibicos well-suited for making ginger beer. Most tibicos contain a small number of *Saccharomyces*, *Candida*, and *Kloeckera* yeast species, along with a majority of *Lactobacillus*, *Streptococcus*, *Pediococcus*, and *Leuconostoc* bacteria. Tibicos is an excellent way to obtain many of the probiotic benefits of other fermented drinks without any of the need to prepare tea or consume an animal's milk. Plus, it only takes one to two days to ferment.

To make tibicos, pour a sweet drink over the tibicos SCOBYs inside of a clean container. Almost any sweet liquid can be used to make tibicos, with coconut water, (low acidity) fruit juice, and nut or grain milks being common choices. If you want to make sugar water, any sugar can be used as long as it offers sufficient carbohydrates (as opposed to stevia, which is not rich in calories). One tablespoon of tibicos grains per quart (liter) of liquid is all that is needed to get the brew going. From here, creativity is the limit. Dried (sulfite-free) fruits can be added to the mix, as can low acidity fruit juices or, really, any other semi-sweet drink. Once the ferment is finished, bottle it and begin a new batch. As with milk kefir, tibicos grains must be constantly fed and monitored, lest they die from prolonged exposure to an acidic environment.

Spirits and Bread

Of all the world's fungal-based ferments, perhaps none has received more reverence than the intoxicating drinks of mead, wine, beer, and ale. These drinks are found in at least one form in nearly every human culture throughout history, often playing pivotal roles in the creation of the world's art and customs. And yet, as with other ferments, the origin of alcohol is shrouded in speculation. Some have suggested that the first food product intentionally created by humans was a crude wine made from honeycomb and rainwater.

Regardless of origin, the first people to receive the mirth of such a simple drink as bubbling fruit or sugar water were the progenitors of the infatuation for alcohol that has been with civilization since long before its first settlements. These people were the first to realize that such a miracle crafted from sweetened water could uplift the human condition and, as such, was a gift for which offerings of thanks were required.

As human cultures progressed throughout history, so did the art of crafting alcohol. Many historians even consider brewing to have been a major incentive for the development of agriculture around 6000 BCE.[6] As crops became established, so did an increase in grain and flour stocks, leading to the further advancement of baking, which originates at least as far back as the development of the first settled civilizations, if not much earlier. As brewing and baking evolved, their complimentary aspects failed to go unnoticed, both being the products of shared yeasts. By the time of the Mesopotamian culture (ca. 3000 BCE), the byproducts of beverage fermentation were already being used as the starters for leavened dough.[7] Which fungal species dominated these ferments is not easy to determine. At some point, *Saccharomyces cerevisiae* began to arise as the primary yeast in beer and bread. Through the selective culturing of food by early cultures, this singular species seems to have been created under the guidance of human labors, as scientists today doubt that *S. cerevisiae* evolved in natural environments.[8] Working with the fungi, we may influence their future, just as they have so heavily influenced ours in exchange.

In ancient Sumeria, where beer was known as *KAS*, it is estimated that 40% of the culture's barley crop was used to produce a wide variety of beers. Some of these drinks were said to be from the "Nether world," while others were reserved for rituals of sacrifice. Here, beer was shared communally and drunk from large vats with the aid of long reed straws, a cultural motif that can be seen depicted in several scrolls dating from this era.

The Scythians and Celts made drinking cups from the skulls of their enemies.[14]

In ancient Egypt, grains were malted, ground, and then partially baked into loaves flavored

with the juice from dates or pomegranates. These loaves were then broken up and mixed with water to ferment into a drink. The final product, thick and rich, was consumed daily by men, women, and children as a dense source of nourishment and energy.[9] Women, honored as they were in this matriarchal culture, oversaw this entire process.[10] As the Egyptian culture further developed, wine production began to be increasingly incorporated into daily life. By the Early Dynastic period (3500 BCE) sophisticated viniculture techniques such as trellising, grape pressing, and even labeling wine by vintage had become refined practices.[11] Still, beer was the national drink in ancient Egypt and, being considered a staple food item, was much more widely consumed than wine.[12]

As civilizations spread across Asia and Europe in the proceeding centuries, so did the arts of brewing and baking. Along with wine and beer, mead maintained a central role in many cultures, with its earliest written reference being found in the Rig Vedas, the oldest text in Hinduism. In many cultures, the magic of fermentation was attributed to specific gods, a reflection of the power these drinks held over the minds and lives of the people. For the Egyptians, brewing was connected to the goddess Hathor, while the Celtic people recognized Braciaca as the god of malt and intoxication. For the Norse, mead was said to come from the udder of Odin's goat, Heidrun, who grazed upon the Yggdrasil, the tree of life.[13] And in the ancient Mesopotamian story of Gilgamesh, the consumption of seven jugs of beer turned the wild man Enkidu into a human.

A harlot introduced Enkidu to the pleasures of civilization, including the eating of bread and drinking of beer. After eating his fill and becoming drunk on seven jugs of beer, Enkidu took a bath, anointed himself with oil, and became human.
—Story of Gilgamesh

Along with this reverence came an increasing degree of ritual that surrounded the drinking of alcohol and the magic of its creation. In Europe, brewers would place elaborately carved sticks of spruce or birch wood into their fermentation vessels while offering prayers to the spirits, asking them to come and enter the brew to bring about a good and potent drink. When the ferment was complete, the magic stick would be retrieved, dried, and safely stored, preserving the essence of the brew. When the next batch was conjured, the stick was placed within the batch to bless the liquid with yeasts that it secretly contained. For other cultures, the brewing ritual was a loud and elaborate act filled with chanting and dancing. Today, as with most cultures throughout history, libations are often poured over a fire or to the Earth as an offering to the gods or the spirit of deceased kinfolk, just as bread is broken to strengthen bonds amongst new friends and old relations.

Mead (Ambrosia)

"The juice of bees, not Bacchus, here behold,
Which British Bards were wont to quaff of old;
The berries of the grape with Furies swell,
But in the honey comb the Graces dwell."

Mead is the simplest and most ancient alcoholic drink, brewed from the combination of water and honey. If frequently stirred for several days in an open container, honey water will begin to bubble thanks to the blessing of wild fungi. Katz suggests a ratio of 1 part honey to 4 parts water as a basic recipe, though more or less honey can be used to produce a stronger or weaker wine, respectively. If using raw honey, the brewing container does not need to be exposed to the environment during the initial mixing phase as the honey will likely be host to its own blend of fermenting yeasts.

Once the mead is bubbling (or, if you are using raw honey, as soon as it is mixed), the container should be tightly covered with a lid that hosts an air lock. Air locks allow for the pressure of gases that the yeasts produce to escape while minimizing the entrance of oxygen and other microbes into the container. Edible flowers or whole berries are nice additions to a mead and can be added during the initial fermentation period to capture their essence in the drink. If the plant is medicinal, the alcohol in the mead will naturally carry the medicine to create a healing elixir.

For the Celts and Picts of ancient Europe, the mead made from the heather plant (*Calluna spp.*) was one of the most revered of all fermented drinks. In his excellent book *Sacred and Healing Herbal Beers*, herbalist Stephen Buhner notes that this drink may have been central to the sacred life practices and ceremonies of the Druids, so enlightening was its effect. Heather mead may have even been the first fermented beverage in the British Isles, with evidence of its production in Scotland dating back over 4,000 years. Traditionally, the top 2–3 inches of the plant's flowering tops were harvested and used within 36 hours to be the primary flavoring ingredient. Alternately, the honey derived from the plant—unusually thick and gelatin-like from a high protein content—was also used to provide the mead's sugar base, drawing an even deeper connection between the fungi, bees, and this sacred plant. For centuries, heather tops were also used in place of hops to preserve and flavor beers.

Brewer's yeast has the highest glucose tolerance factor (GTF) of any food. The GTF helps the body utilize glucose more efficiently, thus reducing the insulin requirements of diabetics.[18] Yeasts in the Saccharomycotina are one of the few organisms that produce ergothioneine, an amino acid with antioxidant properties.

As the dominant flora in the acidic heathlands of western and northern Europe, wild heather is highly dependent on the ericoid mycorrhizal fungi that transform and transfer nutrients to and from the plants in these unique habitats. Without the support of these hidden fungi, the heather plant would likely fail to flourish in these extreme conditions. And without these fungi, the history and evolution of European spiritual traditions may have been significantly altered. To fully appreciate the reverence long attributed to heather or any sacred flora, the inseparable fungi that permeate the plant's ecosystem should always be recognized. Buhner notes that the fermented drink made from many other plants in the Ericaceae—all associated with ericoid fungi—were also appreciated historically for their highly inebriating and/or sacred properties:

- Bell heather (*Erica tetralix*)
- Yellow rosebay (*Rhododendron aureum*)
- American rosebay (*Rhododendron maximum*)
- Strawberry tree (*Arbutus unedo*) fruit
- March rosemary (*Ledum palustre*)
- Labrador tea (*Rhododendron spp.*), a narcotic
- Whortleberries (*Vaccinium uliginosum*), a narcotic
- Ling heather (*Calluna vulgaris*), a narcotic[15]

Heather Mead

By Stephen Harrod Buhner[16]

Ingredients

- 6 pounds (2.7 kg) heather honey
- 10 cups (2.4 L) flowering tops
- 4 gallons (15 L) water
- Yeast

Process

1. Heat water to 170°F (77°C).
2. Add 6 cups (1.4 L) heather and stand covered overnight.
3. Strain out the flowers and bring the infusion to a boil. Turn off the heat and add the honey, stirring until it is dissolved.
4. Run the *wort* through a sieve filled with 2 cups (500 mL) of heather tips into the fermenting vessel.
5. Allow the liquid to cool, then add 5 grams of dry Windsor brewing (Danstar) yeast.
6. Add an airlock and ferment the mead until bubbling slows.
7. Remove 0.5 gallons (1.9 L) of the mead from the fermenter and add 2 cups (500 mL) of flowers.
8. Warm this portion to 158°F (70°C), cover, and steep for 15 minutes.
9. Filter the tea and, once cool, return the liquid back to the fermenter.
10. When the fermentation is complete, prime bottles, fill, and cap.
11. Allow the mead to age for 2 weeks to 2 years. Enjoy.

Wine

Wines are produced in a manner similar to meads, but instead of honey forming the base for the recipe, plants or fruits serve as a wine's primary ingredient. A wide variety of wine recipes exist but, in sum, most call for 1) combining plant matter/juice/tea, water, yeast, and additional nutrients in a clean container, 2) air-locking the container until bubbling ceases, 3) siphoning the liquid off of the resulting sediment and into a new carboy to increase fermentation, and 4) bottling. These four stages can take weeks to months, depending on the recipe.

For decades, medicinal mushroom extracts (such as those discussed in Chapter 7) have been added to wines and beers in Asia and other countries to provide a medicinal quality to these bev-

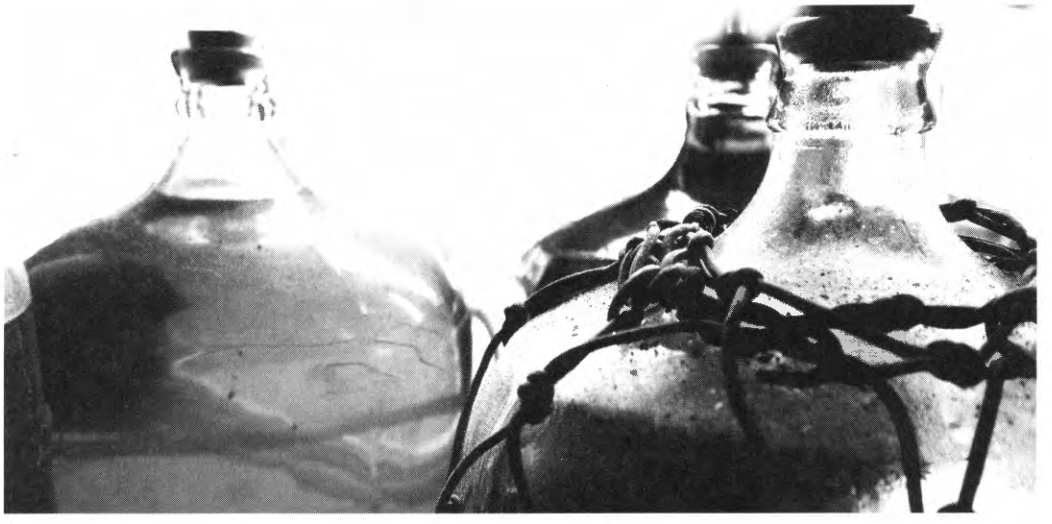
erages. Similarly, medicinal mushrooms have long been used in a variety of mead, wine, and beer recipes to impart a mushroomy flavor and medicinal quality to the drink. However, a study from 2001 found that medicinal mushrooms can be added to wines not just as an additional ingredient, but as the fermenting organism. In the study, the mycelium of *Pleurotus ostreatus*, *Agaricus blazei*, and *Flammulina velutipes* (obtained by filtering from a liquid culture broth) were added to a grape *must* in place of *Saccharomyces cerevisiae*.[17] After several weeks, the resulting wine was found to have a surprisingly high alcohol content in both the *P. ostreatus* (12.2%) and *A. blazei* (8%) wines. The wines were also found to be rather medicinal, with the *Agaricus* wine containing medicinal B-glucan sugars and the wine made from *F. velutipes* producing a thrombosis-reducing effect. More experimentation is needed to explore the vast potential that this singular study suggests for using medicinal fungi in the production of medicinal beverages. I would not be surprised if brewers of the future were to discover that, just as different yeast strains produce different qualities of wine and beer, the mycelium of different mushrooms can also be tailored to create a wide range of medicinal and flavor profiles. If they say a glass of wine a day is good for you now, just imagine the health benefits of the mycowines of tomorrow!

Beer/Ale

The fermentation of grains into the alcoholic drink known as beer requires additional processing stages when compared to the production of meads or wines. Unlike the accessible sugars found in fruits and honey, the carbohydrates of grains are largely locked up in the form of starch, a compound that *Saccharomyces cerevisiae* cannot consume. As such, the starch in grains must be converted to sugar. This can be done by the amylase-producing fungi (such as those found in koji, described later) or by sprouting the grains. Most modern beer grains are treated this way and then additionally roasted (malted) to caramelize the sugars and alter the grains' flavor profile.

Many contemporary beer recipes exist, though most call for grinding these malted grains and then brewing them into a tea (called a wort) to which hops are added for flavor, bitterness, and aroma. Once the wort is cooled, yeasts (packaged or wild) and other ingredients are then added. The whole mix is then fermented in a container for a few days or weeks and, once bubbling subsides, is then bottled to carbonate. As the beer ferments, the yeast imparts ethanol as well as isobutanol, diketones, diacetyl, isobutyraldehyde, and methylglyoxal as sources of flavor. During this process, the yeast converts, per liter, about 100 grams of sugar into 50 grams of CO_2 and 50 grams of ethanol.

Around 90% of global beer production is of lager beers (made with the bottom-fermenting yeast *Saccharomyces carlsbergensis*), 5% is of ale beers (made with top-fermenting yeasts, e.g. *S. cerevisiae*), and the rest are mixed or spontaneous ferments made by yeasts and bacteria. Artist's Conk was historically used as a replacement for hops in English style ales. Robert Rogers also suggests using Chaga for this purpose.



Reishi Ginger Turmeric Pale Ale

By Willoughby Arevalo, Max Brotman, and Claire Brown

This refreshing beer is spicy, crisp, aromatic, earthy, and a little bitter. It will make you want to take your medicine. The amount of Reishi used is calculated to give a 4 gram dose per 12 ounces (350 mL) of beer, the daily dose recommended by Robert Rogers in The Fungal Pharmacy. *As everyone's brewing setup and process is a little different, this basic recipe has been left open to interpretation. If you are unfamiliar with beer brewing, consult your local brew shop, a home brewing book, or one of the many online brewing forums.*[19] *Also, feel free to just wing it. Makes 5 gallons (19 L). Partial mash.*

Ingredients

- 6 pounds (2.75 kg) light malt syrup
- 2 pounds (900 g) 2-row malt, cracked
- 1 pound (450 g) Munich malt, cracked
- 0.5 pounds (225 g) dried Reishi, finely cut or coarsely ground
- 1 pound (450 g) fresh ginger rhizomes, grated
- 0.75 pounds (340 g) fresh turmeric rhizomes, grated (if you can't get it fresh, try using 0.5 cups [225 mL] dry turmeric powder)
- 1 ounce (30 g) hops for bittering (such as Challenger)
- 1 ounce (30 g) hops for aroma (a citrusy type, such as Centennial)
- 1 packet American ale yeast (or culture your own)
- 4.5 ounces (183 g) light dry malt extract (for bottling)

Decoct

1. Put the Reishi, ginger, and turmeric in a large, non-reactive pot (or a crock pot) with about 1 gallon (4 L) of water, and simmer for 2–24 hours, adding more water if necessary to maintain the volume.

Mash

2. Fill your kettle with about 2 gallons (8 L) of water and heat to about 160°F (71°C). Simultaneously, heat 2 gallons of sparge water to about 160°F (71°C) in another pot.
3. Put the grains in a sac and submerge it in the first kettle, dipping and swirling the sac to thoroughly wet the grains. Suspend the sac from a wooden spoon laid across the top to keep the grains off the bottom while they cook.
4. Watch closely and maintain the temperature for 30 minutes.
5. Alternately, do your mash in a food-grade plastic bucket, which will hold the temperature pretty well.
6. Remove the grain sac and put it in a large colander perched atop the kettle, allowing it to drip back into the kettle.

Sparge

7. Pour the second pot of water through the grains to rinse out the remaining sugars.

Boil

8. Add the malt extract syrup and the Reishi-ginger-turmeric decoction (including the solids) to the kettle, to make a total volume of about 5 gallons (19 L).
9. Bring the wort to a boil and add the bittering hops (or slow hop, adding hops little by little throughout the boil, starting with the bittering hops and keeping some aroma hops for the end).
10. Boil for one hour.

Closing loops, the grains that are leftover from beer brewing can be used to grow mushrooms.

Finish

11. Turn off the heat and add your finishing (aroma) hops. Cover and chill.
12. Once cooled to 70–75°F (21–24°C), strain out the solids and transfer to your primary fermenting vessel.

13. If you want to calculate the beer's alcohol by volume, take a hydrometer reading of the original gravity.
14. Pitch the yeast, ferment, and bottle as usual. If the ginger and turmeric flavors aren't strong enough for you, juice some and add it to the beer just before bottling.

Before S. cerevisiae *became the preferred yeast among brewers, many of the traditional saisons or lambics of Belgium were fermented, at least in part, by yeasts from the genus* Brettanomyces. *The spicy, earthy, and sour flavors produced by these fungi have in recent years come back into popularity among brewers seeking to produce ales with a more traditional flavor.*

High Proof Alcohol

All alcoholic drinks can be distilled to produce high proof alcohols using a tabletop distillation train (as described at the end of Chapter 7) or large still. Some home distillers and bootleggers convert a metal keg or pressure cooker to serve this purpose. Building a still and safely distilling alcohol is beyond the scope of this book, but information abounds on the internet.[20] The home production of high proof alcohol is illegal in some countries.

High proof alcohol, whether homemade or purchased, is a wonderful medium for carrying the medicinal qualities and flavors of fungi. One example recipe is to soak 1 part dried *Boletus edulis* mushrooms in 4 parts sherry (the distillate of wine) for a few weeks before filtering out the solids. The iterations of this concept are limitless.

Jelly Fungi Shots

By Willoughby Arevalo

In Traditional Chinese Medicine, jelly fungi are considered cooling and drying. Eaten fresh in the field, they are earthy and refreshing. I call them "forest floor-flavored gummy bears." This decidedly untraditional recipe lies somewhere between food, medicine, and adult beverage.

Ingredients

- Fresh jelly fungi in any combination of the following species: *Dacrymyces palmatus, Ductifera pululahuana, Guepinia helvelloides, Heterotextus alpinus, Pseudohydnum gelatinosum, Tremella fuciformis, T. lutescens,* or *T. mesenterica*
- Liqueur of your choice

Process

1. Clean the mushrooms if necessary. This is one instance where washing mushrooms in water may be appropriate.
2. Place in a clean jar and cover with liqueur.
3. Infuse for 1–7 days at room temperature. The alcohol will absorb into the fungus and some of the medicinal properties will be extracted into the liqueur.
4. Transfer to the freezer, where they will keep up to six months. The high alcohol content should prevent freezing.
5. Serve ice cold with a spoon or in a cocktail.

Bread

For the majority of recorded history, the breads of the world have largely been leavened by the actions of wild yeast-based sourdough cultures. It was only around two centuries ago that this practice changed as bakers and food scientists began to work with isolated yeast strains for baking practices. As opposed to pure yeast cultures, the integration of sourdough starters into breads and other pastries is an ancestral and natural process that can be performed by anyone on the globe through the use of just a few simple ingredients.

To make a sourdough starter, first mix flour and water into a smooth paste that is easy to stir, yet thick enough to cling to the stirring spoon. Leave the mix covered with a cloth but exposed to the open air to help introduce wild yeasts. Vigorously stir the mixture often until the starter begins to bubble. At this point, the culture should be continuously fed to help maintain its activity; most recipes call for tripling the starter volume every day or so. Once the mix is bubbling and smells slightly sour, it is ready to use in a recipe. Once incorporated into a bread mix, the yeasts will expel CO_2. If the bread is made with grains that contain gluten, this sticky protein will work to trap the gas and stretch upward, thereby causing the bread to rise. For gluten-free breads, ingredients such as xantham gum are used to perform this same gas-trapping function.

A sourdough starter can be fed and expanded indefinitely. Indeed, some bakeries in Europe still use heirloom sourdough cultures that have been maintained, shared, and traded around the world for over a hundred years. However, as sentimental as these elder cultures can become for their inheritors, it should be realized that if the starter changes location its fungal and flavor profile will alter as it incorporates the microbes of its new environment and substrates. As cultures move around the world, they are shaped and modified by the influences of their surroundings and citizens.

Gluten-Free Sourdough Teff Bread

By Rowan

Dries

- 1 cup (250 mL) teff flour
- 0.75 cup (180 mL) white rice flour
- 0.25 cup (60 mL) brown rice flour
- 2/3 cup (160 mL) potato starch
- 1 teaspoon xanthan gum
- 0.5 tablespoons salt

Wets

- 1 cup (250 mL) water
- 1 cup (250 mL) sourdough starter
- 2 eggs
- 0.25 cup (60 mL) oil or fat

Process

1. Combine and sift or whisk the dry ingredients until all of the potato starch clumps are gone.
2. In a separate bowl, combine the eggs and oil and whisk.
3. Add the sourdough starter and water, and whisk until combined.
4. Combine the two mixes thoroughly. This may be easier to do with your hands rather than with a spatula or spoon.
5. Scoop the dough into an oiled pan and sprinkle with sesame seeds. Wait 8–14 hours for the bread to ferment and rise. The bread will not over rise and fall like wheat breads. To speed up the rising process, make a rising chamber by placing the bread in a oven with a pot of water that you just brought to a boil. This will heat and humidify the oven. You can make the bread rise in just a few hours using this technique, but it will be substantially less sour.

Check out more of Rowan's work at bakinginslippers.com.

6. Preheat oven to 400°F (200°C).
7. Bake the bread for an hour or until the top is thoroughly brown and the sides are golden brown and slightly hard or crunchy to the touch. If the sides are soft, keep baking the bread. It is more difficult to see the brown color with dark teff (which is more common) than with light or "ivory" teff.
8. Remove the bread from the oven, flip it out of the bread pan, and let it cool on a rack. The bread is best once is has cooled completely as it can be gummy while it is still hot.
9. Share it with friends and eat it up good!
10. Turn mistakes or old bread into french toast. It's worth botching a batch just for this!

Sourdough starters can be frozen or dried to allow for storage or easier transport.

Culturing Yeast

For the hardcore beer or bread brewer, commercial or wild yeast strains can be cultivated on agar and preserved as stock cultures using many of the same techniques and equipment used for mushroom cultivation. With an understanding of how to cultivate mushrooms, the simple practices for growing yeasts (readily found online[21]) are quite easy to understand.

The following is a simple technique often employed by home brewers to expand a commercial yeast stock into a large amount of starter yeast for a batch of beer. Rather than pitching a small packet or vial of yeast into a freshly brewed wort, beer brewers will first grow a starter of yeast in a "mini beer." After a day of growth, this starter is then pitched into a fresh wort to decrease the fermentation time along with the "off flavors" that can result from the growth of wild yeasts. Of course, if you prefer the taste of wild yeasts, this process (or using a commercial yeast for that matter) is optional. If you are not yet familiar with mushroom cultivation or some of the tools mentioned below, come back to this section after reading Chapter 8.

Materials

- Stir plate (see *DIY Stir Plates*)
- Stir bar
- Commercial yeast packet or vial
- Dried malt extract
- 0.5 gallon (2 L) jar with filter lid used for mushroom cultivation
- Water

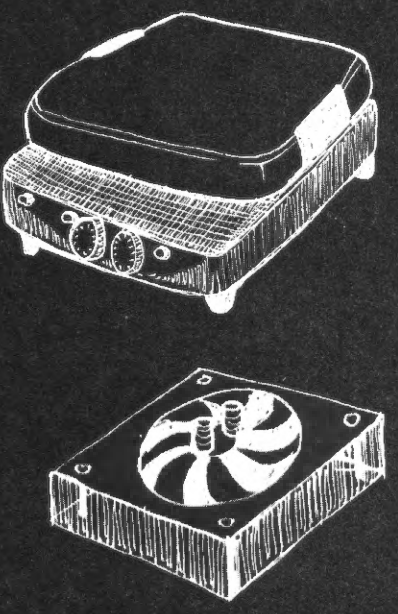
Method

1. Clean all materials thoroughly.
2. Dissolve 0.5 cups (120 mL) dried malt extract in 2 cups (475 mL) of water over low heat and bring to a boil for 10 minutes.
3. Add this mix to the clean canning jar along with a stir bar.
4. Swirl in an ice bath until cooled to around 75°F (24°C).
5. Pitch the yeast and screw down the filtered lid.
6. Place the jar on the stir plate and set to stir for 24 hours.

DIY Stir Plates

Commonly used for culturing yeasts and making liquid inoculum for mushroom cultivation, the magnetic stir plate is a central tool in any fungal cultivation practice. As their name implies, these tools host a spinning magnet that, for the purposes of this book, is used to rotate a magnetic stir bar placed inside a jar of liquid. As the bar spins, a vortex is created in the liquid that breaks the surface tension of the water and allows oxygen to dissolve and the fungus inside the liquid to breathe. Lab grade stir plates can be purchased and often host an additional heating function, which is useful for performing distillations. However, for most of the standard cultivation practices described in *Radical Mycology*, this heating function is not necessary.

A great alternative to buying a commercial stir plate is to build your own. Many designs exist for DIY stir plates but most revolve around gluing strong magnets to a computer fan. Additionally, the speed of the fan can be controlled with the use of a rheostat. This basic design can be made with one fan, or multiple fans can be wired in parallel to run off of a single power source.



Tempeh

Tempeh is a traditional Indonesian dish made from legumes and/or grains that are covered and bound by the mycelium of the mold *Rhizopus oligosporus*. To folks in the West, the concept of moldy food can sound unappealing, conjuring thoughts of fruit turned fuzzy or bread gone green. However, in countries where moldy foods like tempeh and koji form the backbone of many dishes, the cultural connotation with mold is often much more positive and embracing than that in the West. In countries such as China, Japan, Korea, and Indonesia, these micro fungi are not reviled but respected for the nourishment and umami-rich flavors they provide to cuisine. In Guyana, a *Rhizopus* species is even used to create a fermented cassava drink known as Parakari.[22]

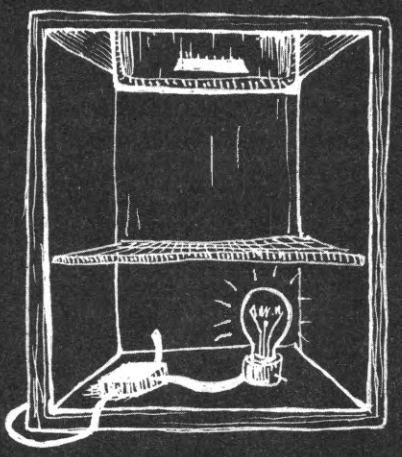
Whether cooked on its own or used as a "flavor carrier," tempeh is a delicious, versatile food in the kitchen. And, like most ferments, it can aid in one's digestion and absorption of nutrients due to the mold's pre-digestion of the grain/legume base. Tempeh can be made with any grain or legume, as well as other ingredients, creating an array of potential recipes and types of tempeh. In Indonesia, soy is often the main ingredient.

To make tempeh, first soak grains or legumes overnight. The beans must be slightly acidified in the soak, so as to prevent the growth of competitor microbes and to create a low pH environment that the mold prefers (around 4.5–5.3 pH is ideal). One way to lower the bean pH is to add vinegar (at a rate of two tablespoons per pound [0.5 kg] of dry beans) to the soaking water. The next day, rub the beans under water to try and remove as many of their hulls as possible. This can be a bit time consuming, making the use of cracked beans or grains a nice alternative to whole beans. Skim off the hulls, then drain and cook the beans in fresh water until they are soft enough to bite through, but not so soft that they fall apart. Drain the beans and cool them on a clean towel until they are approximately 90°F (32°C). Inoculate the beans with commercial tempeh starter at the recommended ratio the package suggests. Finally, pack the inoculated beans into plastic food storage bags that have had holes poked in them with a fork. Press the beans together and set them inside an incubator (see *Incubators*) at 80–90°F (27–32°C) for 24 hours.

Incubators

The incubators used for the cultivation of fermenting fungi or mushrooms come in a variety of forms. All of the designs below work well to hold heightened temperatures and their basic concepts can be elaborated upon to create incubators of all sizes.

Pilot Light
The pilot light of many gas ovens constantly radiates the temperatures that are needed to incubate fermented food or fungal mycelium. Using a thermometer, check your oven to see what its average temperature is. If the oven is too hot, simply crack the door open.



Hay Box and The Bomb
Whether lined with hay, Styrofoam, or newspaper, an insulated cardboard or wooden box can efficiently hold the heat of whatever is put into it for an extended period of time. Temperatures can also be further retained in the box by the addition of plastic bottles filled with hot water. These can be manually filled and replaced as needed, or an aquarium heater rod can be placed into a two-liter soda bottle filled with water to serve as a constant warmth source. Alternately, this box can be fitted with a clear lid and placed in the sun to act as a "solar cooker."

Incubator Cooler, Mini Fridge, or Deep Freezer
This more elaborate design is heated by an incandescent light bulb that is plugged into a thermostat.

The next day, the tempeh should be ready to eat. Frying or steaming strips are popular cooking methods. If you are not going to cook the tempeh immediately, be sure to freeze it to stop the mold growth. Alternately, the tempeh can be left to incubate for several more days, at which point it will develop a layer of black spores on its exterior. This black layer can then be cut off, dried, and used as starter for the next batch. The tempeh below the black layer would still be good to eat.

A more rigorous means of producing starter is to sterilize jars filled with water and rice (at a ratio of 10 parts rice to 6 parts water) in a pressure cooker for 45 minutes at 15 psi. Allow the rice to cool, then inoculate the rice under aseptic conditions (similar to mushroom cultivation) and set to incubate.

Traditionally, tempeh cultures are stored on banana leaves as a mixed culture of fungi and beneficial microbes. These other microbes likely contribute to the richer flavor attributed to Indonesian tempeh. The isolation of *Rhizopus oligosporus* from these cultural kin represents a common theme in fermentation food science, and science in general: simplifying and dividing the relationships in Nature to find simple explanations for complex events. The question that must then be asked is, if this monoculture ferment does not contain the multiple contributors found in traditional tempeh, is it truly tempeh? Even in the foods that fungi touch, we can be reminded that in order to build supportive relationships, one should seek to maintain a culture that fully reflects a diversity of abilities offered by all those involved.

Koji

Koji is another moldy ferment. More specifically, it is the product of growing *Aspergillus oryzae* on rice, barley, or soybeans. First described around 300 BCE in China, koji is one of the main ingredients of several culturally important foods from China and Japan, including miso, soy sauce/tamari, douchi, and the rice wine saké.

In a sense, koji is not so much a food product on its own (though it can be eaten). Rather, koji is used to obtain the dozens of digestive enzymes that the fungus produces, most notably its amylases, which convert starch into sugars. Rich in these potent enzymes, finished koji is added to other legumes or grains to break down (or *saccharify*) these new ingredients into an array of products with unique, complex, and oh-so-savory flavors. Many of the umami-rich dishes that lie at the heart of Chinese and Japanese cuisine would not be possible without the incredible digestive abilities of this ancient fungus.

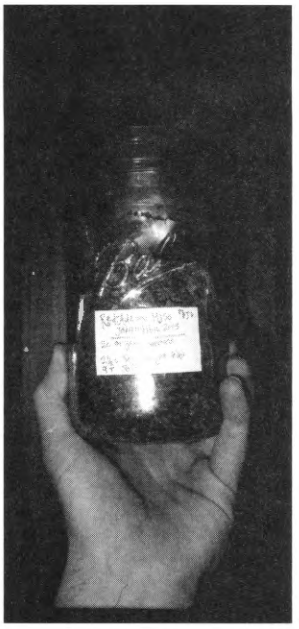
The process for making koji is relatively simple. Grains are soaked overnight and the following day steamed in a bamboo rack to fully cook the grains. Once cooked, the grains are broken up in a bowl where they are cooled to body temperature. When they are sufficiently cool, the grains are inoculated with commercial starter at the ratio recommended by the provider and stirred. The inoculated grains are then wrapped in a clean cloth and placed in an incubator set to 80–95°F (27–35°C). About 24 hours later, once the mix starts to smell sweet and produce its own heat, the cloth is opened and the grains spread out into a layer around two inches (5 cm) thick. This prevents the mold from overheating. The grains are then covered with a clean cloth and turned every few hours until all of the grains are covered with mold. If all goes well, a pile of sweet smelling koji will be the result.

If the koji is made with brown rice, incubated at around 80°F (27°C), and left to grow for an extra day or two, olive-green spores will begin to form on the rice. This spore-covered mix can then be used as the starter for future batches of koji. DIY for life! It is best to then dry the spore-covered rice at around 110–115°F (43–46°C) before storing. Hardwood ashes can also be added at a rate of 1.5% by volume to the rice prior to inoculation. This will provide the mold with additional trace minerals and enhance the quality of the starter.

Miso

Miso is a bean paste that has been "double fermented" by koji and lactic acid bacteria. A useful condiment in the kitchen, miso has also been shown in recent years to provide pronounced health benefits. It is said to relieve fatigue, regulate intestinal functions, help with digestion, lower cholesterol levels and blood pressure, protect against gastric ulcers, and even prevent cancer. Miso also seems to significantly reduce the effects of ionizing radiation exposure. This last attribute was first recognized in post World War II Japan where regular consumers of miso were found to lack the

acute radiation poisoning afflicting the rest of the citizens in Nagasaki. A 2013 study found that these anti-radiation effects are directly attributable to the fermentation products of miso,[23] most notably the Kojic acid (5-hydroxy-2-hydroxymethyl-4-pyrone) produced by the mold.[24] Miso is a multipurpose culinary ingredient that can be used to form the base of soups, spreads, glazes, marinades, and much more.



To make miso, beans that have been cooked and mashed are mixed with salt, koji, and little bit of miso (which adds the fermenting bacteria), and then packed into a crock for several months or years. There are several types of miso, each varying in the ratio of these ingredients as well as the length of fermentation. A basic recipe offered by Katz is to soak two pounds (1 kg) of beans overnight and then cook them the next day in fresh water until they are soft. Strain the beans, preserving most of the bean water while also using some of it to dissolve 0.25 pounds (0.1 kg) of salt in a separate bowl. Mash the beans to a paste until they have cooled to around 130°F (54°C). Mix in two pounds (1 kg) of koji, a tablespoon of miso, and the salt water made earlier. Stir well, then pack it all into a clean crock with a weight firmly secured on top. If all goes well, the miso should be ready in about two to six weeks. Any liquid that forms on the surface of the miso is known as tamari and can be collected and savored as a bonus condiment.

Amazaké

Amazaké is a sweet pudding or drink made from rice that has been heavily fermented with koji. Simple to make, the basic amazaké recipe calls for cooking sweet brown rice, cooling the rice to around 130°F (54°C), mixing in some koji, and then incubating the mix for 8–20 hours at 140°F (60°C) until the desired consistency and flavor is achieved. The longer the mix ferments, the more liquefied it will become. The ratio of koji:rice is quite variable. Mixes anywhere from 1:8–2:1 work well, with higher amounts of koji leading to a faster ferment. Once the amazaké is ready it should be eaten directly, frozen, or cooked to end the fermentation. Other grains can be used as well. Experiment!

Moldy Cheese

Last, but not least, another common fungal ferment are the two main types of moldy cheeses: the creamy white rind cheeses, such as Camembert and Brie, and the stinky, love 'em or hate 'em blues—Roquefort, Gorgonzola, and Blue Stilton. For both types, the first step is to obtain cheese curds. Curds can often be bought fresh at a high quality cheese shop or, better yet, made at home with the use of rennet and a lactic acid starter (e.g. milk kefir).[25] Once you have obtained curds, the next step depends on what type of cheese you want to make.

For white cheeses, the curds are pressed into a cheese mold and then sprayed with a liquid suspension of *Penicillium camemberti (P. candidum)*. Within days, the fungus will form a white rind around the curds and slowly travel into the center of the mass to digest the mass. Depending on the type of cheese desired, the ferment may be done after as little as three weeks.

Blue cheeses are all made with the mold *Penicillium roqueforti*. Rather than being applied externally, these spores are mixed into the curds before pressing. If all goes well, a mycelial rind will form to hold the curds together and protect them from other microbes as the cheese matures over the course of 6 weeks or longer.

Ingredients

- Clean, non-pasteurized blue cheese
- Water
- 2 teaspoons salt
- Fresh cheese curds

Process

1. Cool the curds in your refrigerator.
2. Add salt and mix to form small, pea-sized pieces of curd.
3. Blend 1 teaspoon of the blue cheese in 0.25 cups (60 mL) of cool water. Be sure to

use a piece of cheese that is darkly colored, signifying lots of spores.
4. Pour this blue water (spore inoculum) over the curds and mix.
5. Place the curds into a cheese press and allow the mix to settle overnight.
6. Remove the inoculated curds and poke air holes through the cheese every inch (2.5 cm) in all directions using a 0.25-inch (0.6 cm) wide, sterilized metal rod.
7. Rub the block with salt and wrap with a clean handkerchief.
8. Place the block in a cool, humid space (around 50°F [10°C]/70% humidity is ideal).
9. Flip the cheese daily and replace the handkerchief if it is wet.
10. In 7–10 days a rind should start to form. Allow the cheese to age for two months before sealing in wax and storing.

Other Fungal Ferments

Sufu (East Asia)

A form of fermented soybean curd, sufu is made by inoculating dry firm tofu with the spores of *Actinomucor elegans, Mucor sufu, Mucor rouxanus, Mucor wutuongkiao, Mucor racemosus*, or *Rhizopus* species and then soaking the tofu in a brine of rice wine, vinegar, chili peppers, or sesame oil.

Ragi Tapai (Across eastern and southeast Asia)

Ragi tapai is a term applied to the fermentation of various carbohydrate-rich foods including cassava, cooked white rice or glutinous rice, and sweet potatoes. The food is cooked, cooled to about 85°F (30°C), and then inoculated with a variety of molds, including *Aspergillus oryzae, Rhizopus oryzae, Amylomyces rouxii,* or *Mucor* species, as well as yeasts such as *Saccharomyces cerevisiae, Saccharomycopsis fibuliger*, or *Endomycopsis burtonii.*

Ang-Kak (China)

Also known as red yeast rice, ang-kak is made by inoculating non-glutinous rice with the mold *Monascus purpueus.* Red yeast rice has been used since at least the Tang Dynasty in China (ca. 800 CE) as a medicine for invigorating the body, improving digestion, and revitalizing the blood. It has also been used traditionally as a red dye source for food, wine, and fabrics. More recently, ang-kak has been shown to produce cholesterol lowering statin compounds.

Soy Sauce, Tamari, Shoyu, and Kecap (East Asia)

These related sauces are made from the fermentation of soybeans by *Aspergullus oryzae* or *A. sojae.* Similar to the production of miso, the cooked soybeans are inoculated with koji and left to ferment. After the mix has fermented for several weeks or months, the liquid is pressed out and the solids discarded. These sauces are particularly flavorful due to their strong umami taste, derived mainly from the actions of the fungus.

Katsuobushi (Japan)

Katsuobushi is a Japanese dish of fermented skipjack tuna (*Katsuwonus pelamis*). The fish is prepped, smoked for a few hours per day over the course of a month, sun dried, sprayed with *Aspergillus glaucus*, and finally left to ferment for two weeks. The mold is then scraped off and the fish is further sun dried to create a tough, woody food that is mainly used as a minor ingredient in recipes. The fermentation process may also be repeated several times, creating an increasingly flavorful—and expensive—condiment. Shaved *katsuobushi* (a.k.a. bonito flakes) and dried kombu kelp are the main ingredients of *dashi*, the broth that is commonly used as a base for miso soup.

Chapter Seven

The Pharmycopeia

Fungi are the grand healers of the world. Theirs is a medicine of uniting, drawing in, and deep cleansing that tonifies whole ecosystems and raises the vitality of all those with whom they synergize. For the individual, fungi can be worked with in the body ecology to uplift one's physical and energetic health in powerful ways that are not readily equated by medicinal plants alone. Indeed, the medicinal yeasts that cover wild fruits and the endophytes that live inside of foraged plants have likely been the source of many of the medicinal benefits long attributed to plants. Invisibly and subtly, the healing fungi have always been a part of our foods and medicines. The history of health is a history of the fungi.

Origins

The first occurrences of humans intentionally working with medicinal fungi date back to the origins of human civilization itself. To our ancestors, the heavenly ferments were long recognized for their healing abilities, and when they or other crops fell to decay, new medicines were found waiting in their decomposition. The antibiotics produced by mold-covered breads and grains were highly regarded by the ancient Egyptians and the writers of the Talmud, who would rub these micro fungi on wounds to fight off infections.[1] What a small miracle it must have been to witness this internally nourishing food transform into a cure for external maladies. Moldy bread is such an effective disinfectant that its application was continued for thousands of years until at least as late as the 17th century CE.[2] Today, some of the most important antibiotics are still produced by micro fungi—most notably by several highly productive molds in the genera *Penicillium* and *Aspergillus*—albeit by slightly more refined means of cultivation.

The macro fungi—the mushrooms—occupy a special place in the history of natural medicines, with one of the oldest and most reverential written accounts of their use being found in the first materia medica of ancient China.[3] This text, known as the *Shennong Bencaojing* or Herbal Classic, is said to have been written by the Divine Plowman Emperor, Shen Nung, in the 28th century BCE.[4] Among its 365 entries, six species of fungi are listed: *Calvatia lilacina, Ganoderma lucidum, Grifola umbellata, Polyporus mylittae, Wolfiporia extensa,* and *Tremella fuciformis*. The Herbal Classic later helped lay the foundation for Traditional Chinese Medicine (TCM), an energy-based healing modality that uses natural substances, physical movement, and bodily stimulation to balance and enhance one's life force, or *qi*. As TCM developed over the millennia, Buddhist monks travelling between monasteries transmitted the system throughout ancient Asia. Today, TCM is one of the world's most refined and long-standing traditional approaches to medicine, incorporating a wide array of plants, animals, minerals, and fungi into its hundreds of healing formulations.

Without leaves, without buds, without flowers: yet they form fruit; as a food, as a tonic, as a medicine: the entire creation is precious.

—Engraving from an unnamed Egyptian temple

In the Middle East, the medicinal attributes of desert truffles were first recognized in a *hadeeth* by the prophet Muhammad that states, "The truffles are from Al-Mann [gifted from Allah without

Many other conks were also highly revered by the ancient Greeks and Romans, most notably the Agarikon (above), which was discussed in the writings of Dioscorides (40–90 BCE) and the natural philosopher Pliny the Elder (23–79 BCE).

labor or seed] and its water is a remedy for the eye." The Bedouin people of that region still use desert truffles to treat a range of ailments, including diabetes, stomach distress, skin and eye diseases, and also as an aphrodisiac. And around the globe, the Aborigines of Australia made a similar discovery long ago as they too use truffle juice as a traditional cure for skin sores.

In Europe, the clearest evidence of ancient medicinal mushroom use comes from Ötzi, a frozen man discovered in 1991 on the border of Austria and Italy, high in the Ötzal Alps. Buried in snow for approximately 5,300 years, Ötzi ("the Iceman") was a cultural time capsule of early western Europe. Based on the array of objects he was buried with, he seems to have been some sort of leader or person of high rank in his tribe and, like the Red Lady discussed in Chapter 3, his burial may have been ceremonial.[5] Among his various possessions, Ötzi carried around his waist two medicinal mushrooms: the fire starter Amadou, and the Birch Polypore, which Ötzi likely used to treat his intestinal parasites. The discovery of Ötzi was a major leap forward in our understanding of ancient Europe and the legacy of medicinal mushrooms. But, considering that Ötzi was unlikely to have been the first to discover the uses of the mushrooms he carried, the questions of how ancestral his knowledge of fungi was or where it stemmed from remain unclear.

Considering that the Red Lady died approximately 13,400 years before Ötzi, knowledge of medicinal mushroom must date much further back into antiquity than Ötzi or even records from Asia suggest. While it is unknown for what purpose the Red Lady consumed mushrooms, it is likely that descendants of the Red Lady's tribe discovered that some mushrooms carried medicinal properties within several centuries of the Red Lady's death, if they hadn't already.

Scattered across Ötzi's back, legs, and ankles, researchers found 15 groups of tattoos that at first seemed unexplainable. Consisting mostly of short, straight lines, the tattoos appeared to serve no aesthetic or religious purpose in their placement and initially were dismissed. However, several years later a team of TCM doctors inspecting Ötzi realized that these markings were not randomly positioned but may have actually been involved with Ötzi's personal healing practice. In TCM, the practices of acupuncture, acupressure, and moxabustion use pressure, needles, or heat, respectively, to stimulate areas of an energetic, or meridian, system that circulates qi throughout the body. These practices (and others) move blocked or stagnant qi to bring about healing. What the TCM doctors inspecting Ötzi realized was that the groups of tattoos were placed above the same meridian points that would be used today to treat the chronic pain that Ötzi seems to have suffered from. What's striking about this fact is that the manipulation of meridian energy was not recorded in China until 2,000 years after Ötzi perished, suggesting that the meridian system, or even the concept of a life force, may have not originated in the East as is commonly assumed.[6] If knowledge of the meridian system travelled from West to East, instead of the other way around, so too would have knowledge of medicinal mushrooms. Ötzi very well may have been the inheritor of several healing practices with origins unlike those often assumed by historians.

While Ötzi could have used his fingers or another object to stimulate these meridian points, it is also possible that he used a burning object, so as to produce heat for moxibustion. To the father of Greek medicine, Hippocrates (ca. 400 BCE), the Amadou mushroom was considered to be one of the best sources of heat for moxa treatments,[7] leading me to believe that the Amadou that Ötzi carried was not only used as a utilitarian means for starting cooking fires, but also as a heat source for stimulating his body's vital energy.[8] Amadou is used for this exact purpose by the Sami of Scandinavia today.[9] Ötzi may have used the mushroom as it can smolder for extended periods of time, or he may have used it to light another object or plant material. However, if the mushroom alone was the primary heat source for moxa treatments, this would offer a significant new insight into the history of energetic medicine. For, as moxibustion spread across Eurasia and into regions where Amadou was unavailable, a more consistent alternative would have been sought to take its place. Perhaps this is why in TCM today the fast growing and hearty plant Mugwort (*Artemisia vulgaris*) is the most commonly used source of heat for moxa treatments.

Today, much of the peer reviewed research into medicinal fungi is guided by the insights gained over the last 2,000 years of documentation and research by TCM practitioners. One of the most important modern medicines for multiple sclerosis is fingolimod, an immune suppressant derived from the culture broth of *Isaria sinclairii*, an entomopathogenic fungus that grows on cicadas and

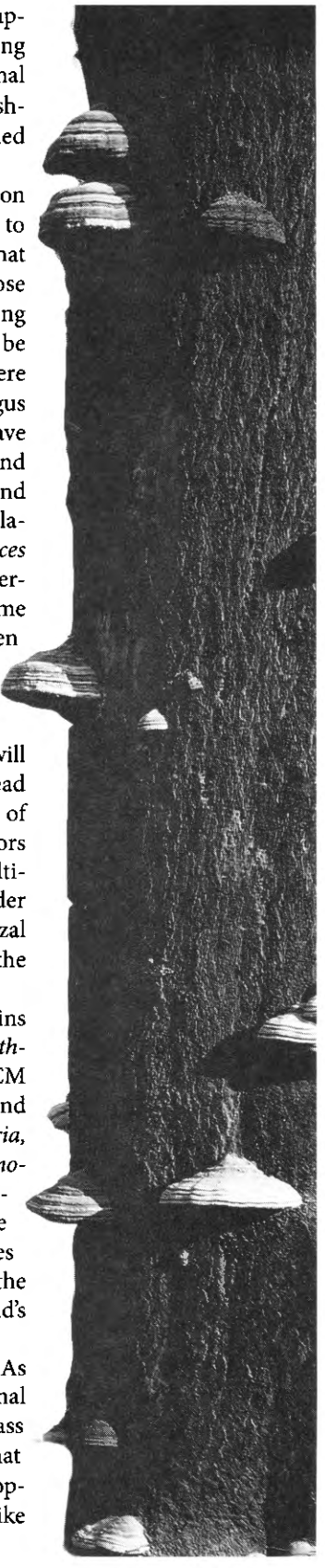
has long been used in TCM as a means for obtaining eternal youth. Cyclosporin, an immune suppressant used to minimize organ rejection after transplants, is produced by the insect-attacking fungus *Cordyceps subsessilis*. Many of the mushrooms that are highly regarded for their medicinal potency were likewise first documented in China and Japan long ago. Much of the medicinal mushroom research today is simply validating what practitioners in this part of the world have claimed in their writings for generations.

The medicinal properties of endophytic fungi have gained an increasing amount of attention in recent decades as their ecological significance has come to light. These fungi have been shown to produce an array of alkaloids, cytochalasins, polyketides, terpenoids, flavonoids, and steroids that have activity against bacteria, fungi, and cancer cells, and also assist in cell division and glucose transport. One of the first insights into the medicinal powers of these fungi came in 1995 during research into the widely prescribed and potent anticancer drug taxol. Originally thought to be plant-derived due to its original source of Pacific Yew tree bark (*Taxus brevifolia*), researchers were surprised to discover that it was actually produced by *Taxomyces andreanae*, an endophytic fungus in the tree.[10] In the subsequent decades, numerous other non-Yew sourced endophytic fungi have been found to produce taxol[11] and a number of other "plant derived" medicines have been found to be produced by endophytes cultured from within those plants. For example, six antifungal and antibacterial compounds have been produced by the fungus *Mycelia sterilia*, cultured from Belladonna (*Atropa belladonna*), and four antifungal compounds have been produced by *Streptomyces aureofaciens*, an endophyte of ginger (*Zingiber officinale*), a plant known for its antifungal properties.[12] The medicines these fungi produce also seem to be intimately tied to their ecology, as some endophytes will not produce certain compounds when they are artificially cultured but only when they are living inside of their plant partner.[13]

This information raises the question of how changes in a cultivated plant's endophytic makeup will alter its medicinal potency when compared to those harvested from the wild. If cultivated plants are grown far from their natural habitat, it is likely that the only endophytes it will share with its wilder kin are those endophytes that are transmitted through seeds. The fungi spread by wind or insects will be left behind, leaving cultivated plants with a radically different blend of endophytes and thus a different chemical constituency. I believe that is one of the major factors influencing the stark variation in potency that herbalists have long noted between wild and cultivated herbs. Likewise, it also seems likely that the potency attributed to wild plants growing under stressful environments may be due, at least in part, to the activities of endophytic or mycorrhizal fungi associated with the plant. Indeed, wherever fungal diversity remains high, so too does the resilience and vitality of the fungi's allies.

If endophytic fungi have secretly played a central role in the history of medicine, the origins of our modern healing practices need to be reassessed. In the book *The Conspectus on World Ethnomycology*, Frank Dugan suggests that the medicinal benefits of many of the plants used in TCM should be considered as products of the dozens of endophytic fungal genera that have been found inside of these plants. These genera include *Alternaria, Aspergillus, Aureobasidium, Botryosphaeria, Chaetomella, Cladosporium, Colletotrichum, Dreschleria, Ellisembia, Fusarium, Gliocladium, Phoma, Spiropoes,* and *Torula*, to name just a few.[14] In allopathic medicine, nearly 75% of all small-weight anticancer drugs are not synthetically derived but are instead produced or inspired by the chemical mastery of the natural world.[15] Many of these compounds are derived from plant sources and, as with taxol, many of these may be the direct product of endophytic fungi. I believe that in the coming decades, increased research into the roles of endophytes will reveal that many of the world's greatest medicines owe their initial discovery to the alchemical mastery of these hidden fungi.

The future of medicinal fungi is one of the many exciting unknowns in modern mycology. As researchers and Radical Mycologists continue to branch out from the historical roots of medicinal fungi (i.e. mold, yeasts, and mushrooms), new insights are sure to be uncovered that will surpass even our most powerful knowledge to date. For example, several recent studies have shown that even the soil fungus *Aspergillus terreus* from the Sonoran desert exhibits potent anticancer properties.[16] What other medicines await discovery in marine fungi, endolithic species, or the yeast-like endosymbionts of insects? Only time will tell.



The Medicine of Mushrooms

Whether wild harvested or cultivated, the identification, cultivation, and processing of mushrooms is one of the easiest, safest, and most potent ways to work with the medicines of fungi. Medicinal mushrooms can fight viral infections and cancers, enhance immunity, and tonify the body's organ and energy systems. Currently, around 700 species are known to have pronounced medicinal effects on the human body, although only a few dozen are currently considered to be the most potent.

To fully appreciate the medicinal properties of mushrooms, it is helpful to recognize that their healing properties are a direct reflection of their habitat. The antibiotic "soup" that each fungus releases to defend itself[7] is a reflection of the fungi's environment, as it is tailored by each hypha to selectively ward off the competitors that are in its immediate area. When a particular competitor predominates, the fungus may shift this bath's composition to one more targeted to that specific competitor. If a human were to consume the mycelium or fruit body of this targeting fungus, the human may receive additional support for her or his own protection against that same microbe. In other words, fungi exemplify a concept commonly expressed in herbalism: the medicines growing near you often meet your health needs better than those imported from overseas.

With that said, it's important to note that where fungal species are scarce or in danger of overharvesting (as with Chaga [*Inonotus obliquus*] in North America and Cordyceps [*Cordyceps sinensis*] in Asia), their cultivation is a wonderful alternative. For the proficient cultivator, growing whole fruit bodies is a worthy effort. However, going through the challenges of fruiting is not necessary for many medicinal fungi. It can be much easier and cheaper to simply grow the fungus' mycelium, which is quite potent on its own. That said, the best mushroom extract will be derived from both mycelium and fruit bodies as both can contain unique bioactive compounds. Still, do not worry about getting the *best* mushroom medicines out of your efforts, just work with what you've got and scale up from there over time. Though the method of preparation does have an impact on the quality of the final product, the most important factor is that you make it, share it, and take it.

The Main Types of Immune Response Cells

Fungi can significantly support the human immune system. As such, it is helpful to have a sense of how the main cell types in the immune system function.

- **T-cells:** T-cells help the human immune system adapt and "update" itself to new pathogens. There are several types of T-cells. The helper T-cell recognizes and marks invading cells to later be destroyed. Cytotoxic T-cells destroy cells that have been mutated by cancer or infected by a virus. Suppressor T-cells reduce hyperactivity in the immune system.
- **Natural killer (NK) cells:** NK cells are part of the innate immune system. They travel in the bloodstream where they detect and kill many types of infectious cells.
- **B-cells:** There are several types of B-cells, but all produce antibodies that bind to and destroy antigens.
- **Phagocytes (macrophages, monocytes, and neutrophils):** These cells engulf and destroy invaders. Macrophages are found in the tissues, monocytes are restricted to the blood, and neutrophils are primarily in the blood but can enter tissues if needed. Macrophages play a particularly important role in the immune system as they both destroy invading pathogens and also help T-cells adapt to that invader, thus enabling the T-cell to recognize the pathogen in the future. Macrophages also alert the immune system to the presence of invaders and trigger the production of more macrophages and T-cells.

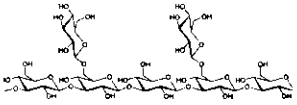
(1,3) Beta-D-Glucans

If any generalizations can be made about medicinal mushrooms it is that they enhance the body's ability to defend against many forms of disease, such as autoimmune disorders, viruses, and various types of cancer. Interestingly, these properties are not so much attributed to enzymes or other chemicals that the fungi release, but to sugars found predominantly in their cell wall. These sugars work by stimulating the production of the various T-cells, B-cells, NK cells, megakaryocytes, myeloid progenitor cells, and macrophages in the body, essentially kickstarting the immune system. Thus, these sugars do not directly destroy cancer cells or other infections, per se, but rather activate the body's innate healing and defense responses. This nonspecific action can support some or all of the body's major systems, including the hormonal, nervous, regulatory, and reproductive systems, depending on the species. They are also non-toxic and place no additional stress on the body. All told, these sugars are an excellent general tonic, especially for people whose immune system has been compromised.

Some plant crops, such as oats and wheat, also produce medicinal (1,3) beta-glucans. However, these sugars have largely been bred out of these plants as they interfere with the processing of many food products.

Structurally, medicinal fungal sugars are rather large and complex. Whereas common table sugar (sucrose) is a disaccharide composed of glucose and fructose with a molecular weight of 342, the sugars in mushrooms are long chains of D-glucose sugars that can achieve a molecular weight of 1.5–2 million, 30–45 times heavier than plant sugars. These fungal polysaccharides are not bonded together like chain links (as with cellulose), but instead connected between their 1st and 3rd carbon atoms in the D-glucose rings, a bonding pattern that results in the sugars forming a right-winding triple helix with a sense and pitch strikingly similar to DNA.[18] In some of these (1,3) beta-D-glucans, short side branches of sugars may also be attached to the 6th carbon in the glucose monomers of the spiral backbone, giving the whole structure a comb-like appearance. These side chains seem to be randomly dispersed and are of different sizes, providing for the creation of thousands of potential sugars. This structural complexity and variability is what allows the sugars to produce a range of effects in the body as each sugar provides a high capacity for carrying biological information.

In general, there is normally a higher amount and diversity of polysaccharides found in the fruit bodies of mushrooms than in their mycelium, with the former being comprised of a mix of galactose, glucose, mannose, and fucose units, while the polysaccharides from mycelia are mainly protein-containing glucans. Each fungal species tends to host its own unique blend of these sugars, with some species carrying particularly potent forms and/or combinations that give them their high medicinal quality. And as the cell wall of each hypha may be comprised of as much as 90% of these sugars,[19] in a sense nearly the entire fungal mass should be considered as pure, potent medicine.



Lentinan

Two of the best-studied fungal glucans are lentinan, produced by Shiitake, and schizophyllan, produced by the Split Gill mushroom. Both of these sugars seem to be T-cell oriented immunopotentiators that increase helper T-cell and macrophage production. These two sugars, along with grifolan from Maitake, have chemical structures that may be identical, however they are referred to by different names in the literature based on their source.

Some polysaccharides bind to proteins, forming a polysaccharide-protein complex (a.k.a. a lectin or glycoprotein). Krestin (or Polysaccharide K [PSK]), produced by Turkey Tail, is a notable and well-studied example of this type of fungal medicine.

To extract these medicines from mushrooms/mycelium, the chitin bonds in the cell wall must first be broken, enabling the sugars or glycoproteins to be released from the wall matrix. Typically (and traditionally) this is accomplished by applying hot water to the fungus in the form of a tea or soup. However, the medicinal sugars that mushrooms produce are not confined to their tissue. They can also be exuded into the substrate of the fungus, whether that be a solid or a liquid. Indeed, many of the most potent medicinal mushroom extracts are simply concentrated forms of a liquid-based medium and/or a preparation of the pure mycelium that was grown in that liquid. These preparations, though commonly crafted in China, are largely absent from Western fungal extracts.

In a strange biotech application of these polysaccharides, the spiral shape of (1,3) beta-glucans is currently being investigated for its potential to enable the formation of artificial nanofibers.[20]

Terpenoids are some of the oldest medications. To cure the common cold, people have been inhaling the fresh resin of pine trees and eucalyptus leaves for hundreds of years. Pine tree resin and eucalyptus leaves both contain terpenoids.

Terpenoids

Along with the beta-glucans, the other major category of medicinal compounds in fungi are terpenoids. Whereas beta-glucans are essentially universal to all fungal cell walls, the terpenoid content of different mushroom species can vary widely in form and concentration. In general, fungal terpenoids are anti-inflammatory and can help calm an overactive immune system (e.g. in the case of an allergic reaction), while not suppressing the immune system from performing its job of protecting the body. In essence, terpenoids help bring the body closer to homeostasis in times of stress and fatigue, while also helping fight disease and prevent inflammation in the body. As opposed to the water-soluble sugars of fungi, "terps" are comprised of 5-carbon isoprene units that make them hydrophobic (non-soluble in water) and, thus, best extracted using a hydrophobic solvent such as drinking alcohol. The medicinal terpenes that fungi produce typically fall into one of three groups:

- **Volatile monoterpenes and sesquiterpenes (essential oils):** There is relatively little research into the medicinal properties of fungal essential oils. Robert Rogers has done extensive work to compile some of the most current information on the topic.[21]
- **Diterpenes:** A small number of fungal diterpenoids have been studied for their medicinal properties. Some are antimicrobial, others are antitumor, and some can inhibit the synthesis of squalene synthase and stimulate opioid receptors. Fungal diterpenoids come with one of several carbon skeletons, the most notable of which are the cyathins that are found in *Cyathus helenae, Sarcodon scabrosum,* and in the liquid culture broths of *Hericium erinaceus* (as erinacine P) and *H. ramosum.* The erinacines are notable for their ability to induce production of nerve growth factor, which can help in the treatment of dementia or other disorders of the nervous systems.
- **Non-volatile triterpenoids and sterols:** The triterpenoids are the most active and well-researched terpenes that fungi produce. Reishi and Artist's Conk produce at least 100 different triterpenoids between their fruiting bodies and mycelia. Other example compounds include the anti-inflammatory polyporenic acids produced by the Birch Polypore and the pinicolic acid from the Red Belted Conk.

Notable Species

In the last hundred years, a significant amount of research into the constituents and actions of a small number of medicinal mushrooms has been conducted in China and Japan. Often, the species selected for investigation are those that have been traditionally revered. While much has come to light from this research, its limited scope (ultimately a product of funding constraints), has left many other species minimally studied at best.

To appreciate the known capacities of a given mushroom, it is important to recognize that what is currently known about a species' effect may not be exhaustive. Many medicinal mushroom studies are not translated into other languages, making them essentially unavailable to readers in other parts of the world. The expensive process of double blind studies also slows the flow of discovery as it inherently limits the scope and number of studies any given researcher can feasibly accomplish. So, while a given mushroom may be known today to only be antiviral, a study done tomorrow may find that a different compound in that species has heart-strengthening properties. And that says nothing of the mushrooms and other fungi that have yet to be investigated for their healing potential.

The following are a small number of some of the best-studied medicinal mushrooms. Other species well worth researching include Lion's Mane, Split Gill, the Oyster complex (*Pleurotus spp.*), Amadou, Agarikon, Chaga, Birch Polypore, Enoki, *Agaricus blazei,* and *Phellinus linteus.*

SHIITAKE (*Lentinula edodes*)

One of the most potent, fleshy, fungal megafood-medicines is Shiitake. An excellent meat substitute, Shiitake is high in vitamin D and all the essential amino acids. It also produces eritadenine, a unique amino acid that some physicians believe lowers cholesterol.

Shiitake is highly regarded for its production of the beta-glucan lentinan. Heat stable, acid stable, and alkali labile, it is a pure polysaccharide that is composed solely of carbon, oxygen, and hydrogen. Among its many attributes is its potent ability to stimulate macrophages, T-cells, B-cells, and NK cells. The fungus also produces the protein-bound polysaccharides LEM and LAP, which have shown antitumor activity. LEM also stimulates the proliferation of specific T-cells that can help counteract hepatitis and block the spread of HIV. Both of these compounds can be extracted from the mushroom's liquid culture broth.

Water extracts of Shiitake have shown growth-enhancing effects on intestinal microflora species, including *Lactobacillus brevis* and *Bifidobacteria breve*. The researchers of this study suggest that Shiitake can therefore act as a pre-biotic on the gut, where it can support beneficial intestinal flora, reduce the harmful effects of certain bacterial enzymes such as β-glucosidase, β-glucuronidase, and tryptophanase, and even reduce the risk of colon cancer formation.[22]

Some of the most potent medicine offered by fungi is found in the ability of some species to act as adaptogens on the body. In TCM, adaptogenic herbs are said to make the body more resilient by strengthening its natural defenses. A more technical description is that adaptogens are innocuous, cause minimal side effects, have a nonspecific action, and have a normalizing or balancing action that helps bring the body into equilibrium. They are believed to let the adrenal glands recharge, control blood sugar levels, and stabilize hormone production. Reishi, Maitake, and Shiitake are considered adaptogens.

MAITAKE (*Grifola frondosa*)

On par with Shiitake for its excellent medicinal and culinary qualities, Maitake is a saprotroph found in aged oak woodlands. Of the many beta-glucans and protein-polysaccharide complexes that Maitake produces, a small number have been identified as particularly medicinal: grifolan, the D-fraction, and the MD-fraction. The latter two have the same beta-glucan configuration, but the MD-fraction is orally bioavailable and more purified.

Research into the D-fraction has shown that tumor inhibition may be attributed to the activation of macrophages, dendritic cells, and T-cells, and to the enhancement of cytotoxicity in NK cells through the production of interleukin-12 (IL-12). The MD-fraction is especially regarded for its anticancer effects as well as its inhibition of HIV. In one study, the administration of 0.17 grams[23] of vitamin C along with 30–60 milligrams per milliliter of D-fraction was as effective against a form of prostate cancer as 480 milligrams per milliliter of the D-fraction on its own. The simple addition of this vitamin enhanced the medicine's effect by 8-fold,[24] potentially by enhancing the antioxidant effect of the mushroom.

When taken with food, the alpha-glucosidase inhibitor in Maitake may help decrease the amount of starch that is digested into sugar. Combined with Maitake's ability to increase insulin (at least in rats), this mushroom may offer significant support to diabetics attempting to lose weight.

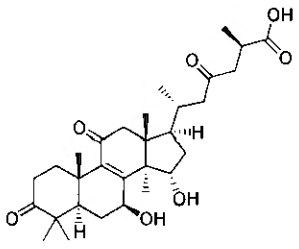
LING ZHI/RESIHI (*Ganoderma lucidum*)

With its high potency and elegant form, Reishi is by far the most revered of all medicinal mushrooms. As a symbol of good health and long life, it is represented throughout ancient Chinese and Japanese art. It was woven into the silk robes and carved into the official scepter of Chinese emperors. At the Forbidden City in Beijing and at the Emperor's Summer Palace, Reishi is symbolized across doors and door lintels, archways, and railings. Reishi has been called the king of herbal medicines and was ranked in the Chinese Herbal Classic as the superior adaptogen, placed at the top of the list above ginseng.

The antler-shaped Rokkadu-Reishi was especially sought out by the ancient Taoists, who claimed that the fungus' qi of the head greatly helped increase one's wisdom and memory. Long-term consumption of Reishi is said to lighten the body and lengthen the years, lending to its alternate names: the "Mushroom of Immortality" and *mannentake*, "10,000-Year Mushroom." It is said that the power of Reishi helps develop the spirit so that one can become a "spirit-being."

Medicinally, Reishi is a bioactive powerhouse producing more than 200 polysaccharides, over 150 triterpenes, significant amounts of the amino acids alanine, leucine, aspartic acid, and glutamic acid, as well as small amounts of polyphenols, steroids, ganomycins, vitamins, lectin, nucleosides,

They dose themselves with the germ of gold and jade
And eat the finest fruit of the purple polypore fungus
By eating what is germinal, their bodies are lightened
And they are capable of spiritual transcendence.
—WANG CHUNG (1ST CENTURY CE), ON THE TAOIST QUEST FOR A HIGHER STATE OF CONSCIOUSNESS.



Ganoderic Acid

nucleotides, and organic germanium. Example bioactive polysaccharides include ganoderan C, ganoderan B, PL-1, SP, ganoderan A, GL-1, PL-3, PL-4, and PSGL-I-1A. Along with water-soluble sugars, these also include bioactive water-insoluble polysaccharides (e.g. hetero β-glucan, manno-β-glucan, xylo-β-glucan, and xylomanno-β-glucan). The mushroom's terpenoids include sterols, lucidenic acids, ganoderic acids (e.g. A, B, C, and D), ganodermic acids, ganoderenic acids, ganodermanontriol, and other oxygenated triterpenes.

This medicinal potency can be tasted in the strong bitter flavor of Reishi, an uncommon feature among medicinal mushrooms. The filtered liquid culture broth of Reishi produces glucoproteins that have been shown to increase swimming endurance.[25] Its water extracts produce anti-HIV effects both *in vitro* and *in vivo*. The many triterpenes of the mushroom are cytotoxic, hepatoprotective, hypolipidermic, antioxidative, and influential in platelet aggregation and histamine release. They are also a tonic to the parasympathetic nervous system and to the adrenal cortex. Reishi is one of the few mushrooms to show medicinal activity in its spores, which have been used to prevent brain damage in a mouse model of Parkinson's disease.[26] Reishi may help with many other acute and chronic conditions including:

- **Nervous exhaustion and adrenal burnout**
- **Allergies**
- **Hypertension**
- **High cholesterol**
- **Nerves and muscles**
- **Pain**
- **Spasm**
- **Arthritis**
- **Myasthenia gravis**
- **Autoimmune diseases**
- **Sjögren's syndrome**
- **Bronchitis**
- **Inflammatory**
- **Hypertension**
- **Viral infections**
- **Bacterial infections**
- **Suppressed immunity**
- **Heart conditions:** Reishi can lower serum cholesterol levels without affecting triglycerides, enhance myocardial metabolism under oxygen deprivation, provide atherosclerosis protection, and improve coronary artery functioning. The effects can be enhanced when the mushroom is consumed in combination with vitamin C and E.[27]
- **UV exposure:** Reishi is considered "radioprotective," meaning it can guard against the harmful effects of UV radiation to the skin and DNA. This suggests an ability to slow aging in the skin and protect against skin cancer.

Turkey Tail (*Trametes versicolor*)

For the ancient Taoists, Turkey Tail was a mushroom of endurance, able to collect *yang* from the base of long-lived and evergreen pine trees from which they sprouted. As such, the mushroom was ideal for patients whose *yang* energy was deficient.

Two primary medicinal compounds that have been isolated from Turkey Tail: Polysaccharide Krestin (PSK) and Polysaccharide Peptide (PSP). Both compounds are protein-polysaccharide complexes, the main difference between them being that PSP lacks fucose and contains arabinose and rhamnose. Unlike most of the other polysaccharides described above, PSK and PSP have a main chain of (1,4) glucans to which are attached to (1,3) glucan or (1,6) glucan sidechains. Both PSK and PSP have been shown to activate T-cells, monocytes, and macrophages, as well as increase interferon-alpha and interleukin-2 production. Thirty-eight percent of PSK is comprised of protein that is rich in aspartic, glutamic, and other amino acids; the rest of the compound is sugar-based. Before taxol was discovered, PSK was the number one anticancer therapy in the world. An abundance of clinical studies investigating the wide ranging medicinal effects of this mushroom have been done in Asia since 1978, but it is only in the last few years that this mushroom's extracts have been recognized by the U.S. FDA for their medicinal value. Both PSK and PSP compounds are exuded into the liquid culture broth of Turkey Tail.

CORDYCEPS (*Cordyceps sinensis*)

Cordyceps species are entomopathogenic fungi that grow from the bodies of dead insects. There are hundreds of *Cordyceps* species, but long ago *C. sinensis* was identified as supreme. First descried in 620 CE during the Tang Dynasty, it is only found in high elevation alpine meadows of the Himalayas and other high mountain ranges in Tibet, Nepal, and China, where it grows from the bodies of the Ghost Moth caterpillar (*Thitarodes spp.*). In TCM, *Cordyceps sinensis* is believed to nourish *yin*, boost *yang*, and invigorate the lung and kidney meridians. To the Japanese, it is known as *tochukaso* ("winter worm, summer plant") and in Tibet it is called *yartsa gunbu* ("winter worm, summer grass").

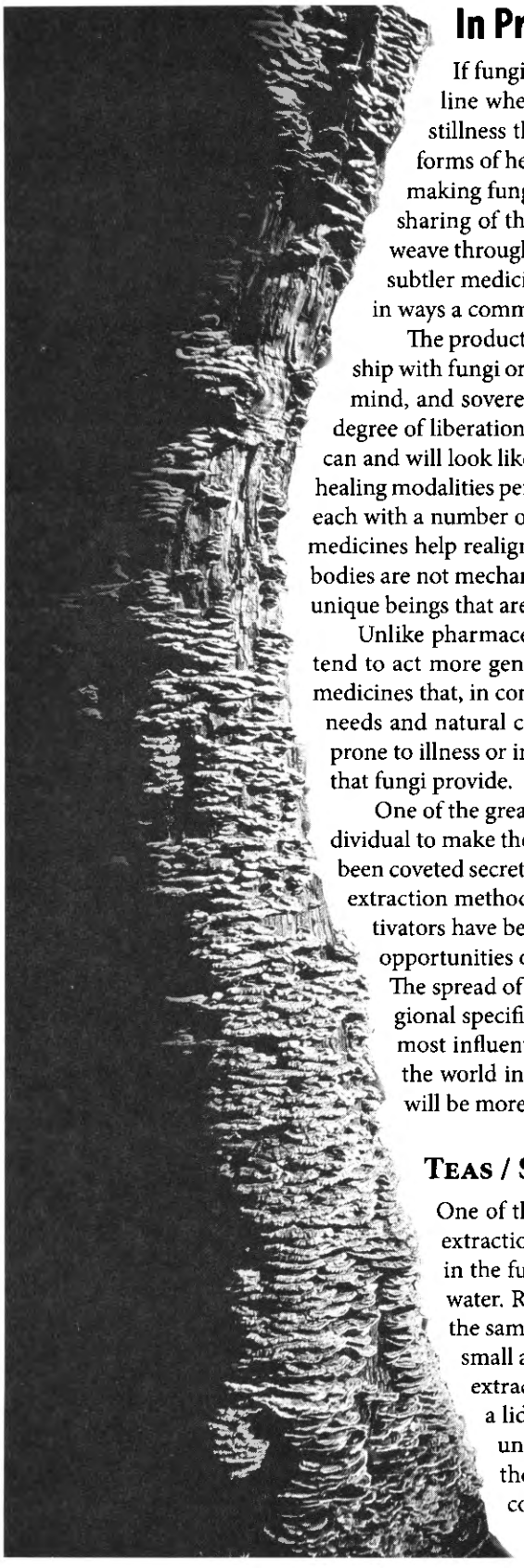
Traditional recipes for Cordyceps include soaking the mushroom in yellow wine to make a groin and knee pain tonic. Alternately, a freshly killed male duck could be stuffed with 8.5 grams of the myceliated caterpillar and its fruit body, roasted, and served as a treatment for cancer or fatigue. After the duck had been boiled, the patient was to remove the Cordyceps and eat the duck meat for 8–10 days until their health increased. The Mykot of Nepal make a yogurt out of Cordyceps and yak milk. Though this mixture lacks the lactic acid bacteria typically needed to coagulate milk, the Codyceps is somehow able to transform the milk into yogurt overnight. The potential health benefits of such a product could be significant, but, unfortunately, research into the production of Cordyceps fermented milk is essentially non-existent.

One of its main medicinal compounds is Cordycepin, a deoxy-nucleoside first extracted from a liquid culture broth in 1951.[28] Cordycepin has shown significant antitumor, antibacterial, antifungal, and antiviral effects. A cardiotonic, it lowers cholesterol and helps control atherosclerosis and arrhythmias. It is ideal for athletes as it minimizes fatigue while also helping increase stamina and oxygenation in the blood. A "sexual potentiator," Cordyceps also increases one's libido and/or sperm count.

Cordyceps mycelium is incredibly easy to grow, especially in liquid culture. However, cultures can be hard to obtain. Historically the Cs-4 strain was considered the most medicinally potent, but more recent research has shown that other strains may be even more active. While research has not determined how to produce fruit bodies of *Cordyceps sinensis* artificially, its mycelium can be grown on grains and processed to obtain the medicine of this fungus. Purple corn, with its high amount of antioxidants, helps increase the growth rate and quantity of active compounds of the fungus, making it an ideal substrate. The most potent compounds are produced when the mycelium is stressed through a stage of growth in which oxygen and light are eliminated and the temperature is reduced. If properly grown, the myceliated grain spawn should be comprised of 5–20% fungal polysaccharides.

TUCKAHOE (*Wolfiporia extensa*)

Though *W. extensa* produces a fruit body, its large, coconut-like sclerotia is regarded as the primary source of its medicinal properties. This is found underground among the roots of various conifers (especially the Chinese red pine and the Taiwanese pine) and oaks. In TCM, it is the most widely prescribed fungus and is said to soothe the heart, refresh the spirit, strengthen vital energy, calm the mind, and to treat diarrhea, spleen dampness, and insomnia. It was historically used in the Imperial Chinese court to prevent wrinkles, pimples, and dark spots in the skin while also promoting healthy, radiant skin. Its rind is used as a diuretic to soothe coughs, while its interior tonifies the heart and supports unease related to pregnancy. The whole sclerotia can be used to treat jaundice and to induce menstruation. Tuckahoe's polysaccharides have strong antitumor and immunomodulatory effects, while the sclerotia's triterpenes (e.g. poricoic acid A) have been shown to be immunostimulating, antiviral, tumor inhibitory, and cytotoxic against various human cancer cell lines.



In Preparation of the Medicine

If fungi are the connecters and healers of whole habitats, where can one draw the line when considering what their medicine is or how to work with it? Is not the stillness that comes from walking in the woods or inhaling the earthy scent of gills forms of healing unto themselves? Though the following sections deal primarily with making fungal extracts that work on the physical body, the collection, processing, and sharing of these products are not divided from the end result. The healing that fungi weave through our lives connect us to place and people, to culture and kin. These are the subtler medicines that working with fungi provides to enrich the mind, heart, and spirit in ways a commercial product never could.

The production of natural medicines is not only a method for redefining one's relationship with fungi or place, it is also an ancient means for commanding control over one's body, mind, and sovereignty. By making medicine, each person is offered the chance to claim a degree of liberation from the monoliths of allopathy by personally defining what one's health can and will look like. Whereas allopathy may define illness as a collection of symptoms, other healing modalities perceive the human as a blend of unique qualities and interconnected systems, each with a number of balance points that can tip unfavorably, causing illnesses to arise. Fungal medicines help realign imbalances and strengthen the human condition, reminding us that our bodies are not mechanical and merely designed for small pills of standardized prescriptions, but unique beings that are healed most profoundly by the living medicines of the planet.

Unlike pharmaceuticals that rapidly alter the body's biochemistry, mushroom medicines tend to act more gently, slowly tonifying the body's systems over time. They are preventative medicines that, in conjunction with a healthy lifestyle, help the consumer tune into their body's needs and natural cycles. The result is increased resilience in the individual who, being less prone to illness or infection, is afforded greater space for honoring the healing and abundance that fungi provide.

One of the greatest outcomes of accessible mushroom cultivation is the ability for any individual to make their own fungal medicines. Whereas many of the following techniques have been coveted secrets for decades, in the open-source era the spread of high potency mushroom extraction methods is an obvious—indeed, necessary—extension of the ethos that DIY cultivators have been promoting for decades. Complimenting this ethic are the innumerable opportunities offered by the reliable, consistent, and safe techniques of liquid cultivation. The spread of these methods into the home- and community-scale production of bioregional specific and pathogen-targeted fungal medicines will undoubtedly be one of the most influential mycelial waves of the future. As this potential reaches further around the world in the coming decades, year-round access to high quality fungal medicines will be more readily available to humankind than has ever been possible.

Teas / Soups

One of the easiest ways to partake of mushroom medicine is to make a hot water extraction. Soaking mycelium or mushrooms in hot water causes the chitin bonds in the fungus' cell walls to break, releasing the soluble beta-glucan sugars into the water. Regardless of the species you are working with, hot water preparations are the same. First, cut the mushroom (or myceliated substrate) into pieces that are as small as possible. The smaller the pieces, the greater the amount of accessible and extractable surface area. Place the mushroom pieces in a pot of water, cover with a lid, and bring up the temperature to around 176°F (80°C) for several hours, until a dark tea is produced. For tough, woody conks, it is helpful to first soak the mushrooms in this water overnight to soften the tissue and hasten the cook time the next day. I also like to leave a crockpot full of mushroom tea constantly running on low to provide a daily source of this warm immune

tonic. Every time I take a cup, I replenish the crockpot with more water to keep it full. Perpetuated in this way, a constant batch of tea can be maintained for many days. Once the mushroom pieces stop producing flavor and color in the water, they can be placed in the compost, made into paper (see Appendix D), or calcined for their salts (discussed later). Alternately, a large batch of tea can be stored in the fridge and slowly consumed over the course of several days.

Tough Shiitake and Oyster stems make a nice addition to a nourishing soup of seaweed, miso, nettles, and other wild greens. Bitter tasting species are best as a tea, optionally masked with honey or other herbs. You can also make kombucha out of mushroom tea, though I have yet to find a definitive answer on whether or not the kombucha SCOBY will alter or consume the medicinal sugars from the tea. Regardless, mushroombucha tastes great.

Chaga Latte

By Willoughby Arevalo

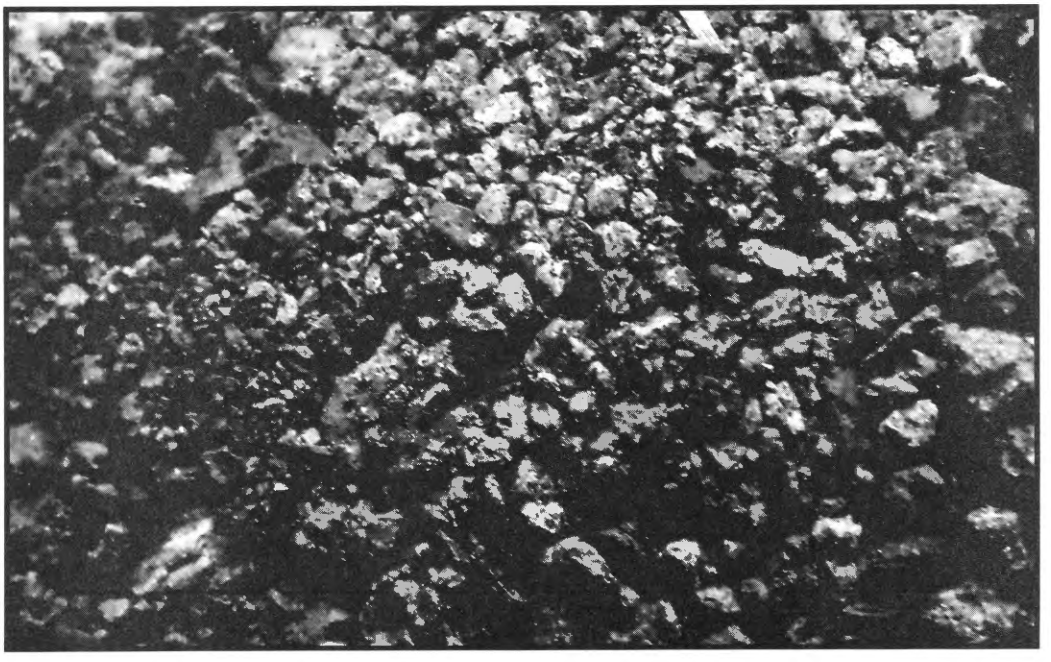
Chaga tea is delicious as is, but this preparation takes its cozy, nurturing vibes to the next level. Feel free to adapt spicing to your preferences.

Ingredients *(per serving)*

- Approximately 0.25 cups (125 mL) Chaga, finely ground
- Water
- 0.5 cups (250 mL) cream, milk, or nut milk
- 1 small cinnamon stick
- 1-inch (2 cm) piece of vanilla bean, or 0.25 teaspoons vanilla extract
- 1 tablespoon maple syrup

Process

1. In an Italian style, stovetop espresso machine, or in a professional espresso machine, brew the Chaga as you would coffee. This results in a thick, potent brew, stronger than that obtained by normal decoction. Unlike coffee, Chaga can be reused several times.
2. Meanwhile, in a tiny saucepan, gently simmer the cream with the spices and syrup. Do not allow it to boil. Alternately use a milk steamer if you have one.
3. Combine the two liquids in your favorite mug and enjoy.



MycoIntuiting and Medicine Circles

When looking at a chart of medicinal mushrooms and their properties, it can be hard to determine which species is best for a given symptom. If five mushrooms are said to be effective against a certain virus, how should a person infected with that virus choose which species or preparation form to take? While one could simply take a blend of all five species, a more focused approach can be used to determine which species and preparation is best for a given individual. By sampling a small dose of a medicine and focusing one's attention on its effects in your mind and body, it is possible to quickly develop an awareness of how your body responds to a particular medicinal mushroom preparation.

This process is quite simple. First, find a quiet place where you won't be disturbed for at least ten minutes. Settle your body into a comfortable position and quiet your mind as best as you can by taking a few deep, slow breaths or lightly fixing your gaze on an object for a few minutes. Once you are relaxed, place a very small amount of the medicine on your tongue (e.g. just a drop or two if it is a liquid), close your eyes, and try to focus on your body and any feelings or experiences that come up. Try to free your mind of any expectations and just sit still, paying attention to how your body responds to the medicine. After a few minutes (or longer), open your eyes and take some notes in a dedicated notebook on what you experienced. Describe any images you saw in your mind or sensations you felt in your body, regardless of whether or not you are able to explain them.

Over time you may come to discover that some medicines affect your body very strongly or that you feel a close affinity to a particular species that you might not have considered previously. As you hone your awareness of your body, the medicines will begin to speak clearly and more directly each time you sit with them. If you find it challenging at first, try to stick with it. Learning to quiet our minds and focus on the messages our bodies are sending us is not a skill that is commonly taught in most modern cultures. But as this is an ancient and innate ability in all humans, it is easy to develop an awareness of what it has to offer, if one is willing to try. In TCM, one's intuition is seen as an attribute of the heart and is associated with the Fire element. By listening to the messages that come from our bodies and hearts, we can gain a deeper relationship with ourselves and with the other beings that we engage with.

This practice can be especially interesting when done with multiple people using an unlabeled medicine. It is quite surprising to see what comes up for each person, how similar the experiences are among participants, and how closely they match the traditional view on the medicine despite each person not knowing what they consumed. Doing these group sessions is also a great way to develop a sense of how a novel medicine tends to affect people.

Triple Extracts

This potent extraction method can be performed on the fruit body and/or mycelium of any medicinal fungus. First, the fungal matter is soaked in cold water to extract water-soluble enzymes and sugars. Then, the tissue is filtered out and placed in high strength alcohol for six or more weeks to obtain the terpenes, sterols, polypeptides, amino acids, and other non-water-soluble compounds.[29] An alcohol extract such as this is known as a tincture. Finally, the mushroom pieces are removed from the alcohol and then simmered in hot water to make a concentrated tea that pulls out the rest of the beta-glucans and polysaccharide-protein complexes. Once each extraction has been made, all three are combined to make a full-spectrum extract that is shelf stable for at least one year. Each extract can also be made in isolation for more targeted therapies, though alcohol is needed for long-term storage to eliminate the chance of the water-based extracts fermenting or denaturing.

If you are seeking to target a specific illness, I suggest doing some research to determine which extraction method is the most effective for the given malady. However, for less targeted therapies, the following is a highly effective protocol for making potent, full-spectrum tonics with wild harvested or homegrown fungi. This process works for mushrooms, myceliated substrates, and the pure mycelium derived from liquid culture broths.

The Cold Soak

1. Cut the fungus into small pieces or, better yet, pulp it lightly in a blender with a little bit of water.
2. Place the material (known as the marc) in a jar filled with 68–77°F (20–25°C) water at a ratio of 1 part mushroom material to 10 parts water (e.g. 10 mL of water for every gram of original mushroom weight).
3. Cover the jar and either stir it with a stir plate (with a stir bar in the container) or occasionally shake it by hand over the course of 6-12 hours.
4. Strain the mushroom material and save the liquid in a sealed jar in the freezer.
5. Once desired for use, thaw the liquid.

The Tincture

1. Place the strained marc in a jar and cover it with strong (ideally 190 proof) alcohol. If this is unavailable for you, strong vodka is a good alternative solvent. If you do not wish to use alcohol, vegetable glycerin can alternately be used, but as it is not as strong of a solvent, it will likely not pull out all of the medicinal constituents that alcohol would.
2. If you have a stir plate, place a stir bar in the jar, screw down a tight fitting lid, and place the jar on the stir plate for 6 weeks. If you prefer a more personal relationship with the medicine, shake the jar for a few minutes at least once a day for 6 weeks. Alternately, a percolation extraction can be done using a packed glass funnel or tapered jar to speed up the extraction method.[30] For some species, an ideal extraction temperature has also been determined, usually this is a wamer temperature (ca. 150°F [65°C]).
3. Strain the marc and squeeze out as much of the liquid as possible. Tincture presses can be purchased or built to help fully extract the liquid.
4. Record the final amount of liquid and store it temporarily in a sealed jar.

The Decoction

1. Put the marc in the top of double boiler and add water at a ratio of approximately 1:10.
2. Bring the water up to 158–176°F (70–80°C) and simmer it until the volume has reduced by approximately one half.
3. Strain off the mushroom pieces and save the liquid in a sealed jar.

Once the three extractions are made, they can then be combined. Most practitioners combine the water extracts with the tincture at a ratio of 3:7 to make a palatable, shelf stable medicine that is 30% alcohol. If you use an alcohol that is weaker than 190 proof, adjust your recipe accordingly. The ratio of cold to hot water extracts is up to your discretion as well, although hot water extracts tend to be more potent than cold water extracts (but this is not always the case, depending on the species). If the cold water extract has been shown to be minimally active for a given species, this first stage can be skipped. Also, if you have excess material, it may be easier to do The Cold Soak last and combine that freshly filtered water to the cooled hot water and tincture blend. Once you have blended the extracts, place the mix in a sealable, dark glass bottle and label it with the date, species, and extraction method. Optionally, the left over mushroom material can be calcined to retrieve its salts (discussed soon), which can then be added to the mix.

Dosages vary by mushroom and malady. If the flavor is too strong for your liking, these extracts can be diluted in a few ounces of cold water or mixed into gelatin shots at a rate of four ounces of extract per box of gelatin. *¡Buen provecho!*

Customized MycoMedicine

One of the most revolutionary potentials that await the future of medicinal mushroom production is the creation of medicines that are targeted to an individual's specific disease. As noted earlier, fungi produce antibiotics and other compounds that are directed at the microbes and viruses in their environment. When a new microbe is introduced, the fungus can, within several days, begin to produce the correct compounds needed to overcome that specific competitor. This is how asexual molds and the Glomeromycota have been able to defend themselves against the countless strains of pathogens that are constantly evolving in the wild. As the environment changes, so does the fungus' defense patterns and bioactive constituents. For the cultivator, this adaptive ability is witnessed whenever a mycelial mat overruns a mold or bacterial colony on a petri dish. For the medicine maker, this concept can be elaborated upon to produce targeted therapies for any individual.

For example, if a person is infected with a particular strain of the flu virus, a swab of their mouth could be wiped onto a petri dish of a medicinal mushroom. As the mushroom's mycelium encounters that virus on the dish, it would begin to produce antiviral compounds to defend against that particular virus. If the mycelium is kept in contact with the virus, it would keep producing the compound(s), perhaps to increasing degrees of efficiency. Bulked up, the fungus and/or its substrate could then be consumed by the infected person as a targeted therapy. My friend James Weiser first proposed this incredible concept to me in 2013.

Though it has yet to be tested in human trials, I would not be surprised if refined protocols that apply this concept become commonplace in the coming years, especially in the home. This concept easily translates to the home cultivator who, using the advanced techniques listed at the end of Chapter 8, can develop or acclimate fungal strains to a pathogen just as they could for a substrate or chemical. Bulked up into liquid media, these targeted fungal therapies could become the key to optimizing the health of people around the world. Once refined, a liquid-based approach to creating inexpensive and potent fungal therapies that do not assume the costs, side effects, and environmental impacts of industrial pharmaceuticals will, I believe, be one of the most influential advances in mushroom growing and natural medicine production in coming years. The reader is encouraged to help in the advancement of this practice and the spread of its potential to help heal all the people of the world.

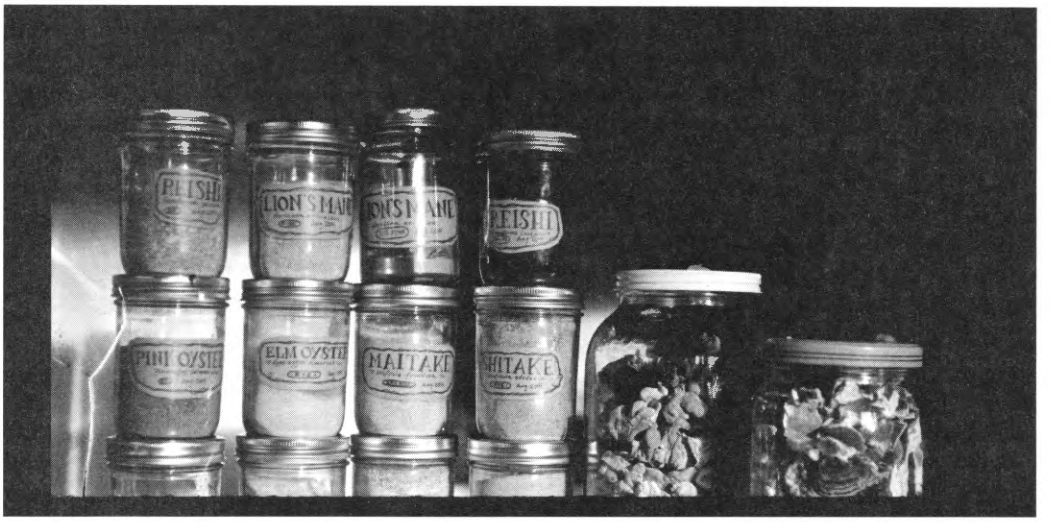
Powdered Grain Spawn

As discussed in Chapter 6, the grain spawn that is produced as a part of the mushroom cultivation process can be consumed on its own as a form of megafood-medicine. Indeed, most commercial medicinal mushroom capsules are filled with powdered grain spawn, with "myceliated brown rice" often being the primary ingredient. In addition to rice, millet and sorghum (milo) are also common substrates. Many of these powdered products are essentially freeze dried grain spawn that has been ground to a fine powder, encapsulated, and then sold at a markup of 1,000% or more! Luckily, comparable products can be made simply and easily at home with grain spawn produced using techniques described in Chapter 8. With these techniques, one cannot only grow their own myceliated grain but also myceliated blends of purple corn,[31] medicinal herbs, and other natural medicines. If these substrates are locally harvested and myceliated with a local mushroom strain, the resulting product would be a potent, place-based medicine that is incomparable to that found in commercial capsules.

Once this substrate has been fully myceliated, it can be processed. First, the material is dried at low heat to minimize denaturing of the active constituents. The grains are spread in a thin layer on a baking sheet or other clean surface and a fan is placed to blow over them for a day or two until they are thoroughly dried. Alternately, the grains can be dried in a food dehydrator on a low setting or, better yet, with its heating element removed. Once the grains are thoroughly dried, they can either be stored whole and used in grain-based recipes as an ingredient[32] or they can be powdered using a blender, coffee grinder, or flour mill. This grinding process is used in place of hot water to

break the chitinous cell walls of the mushroom and make the beta-glucans and other compounds accessible upon digestion. Flour or stone mills are preferable as they produce the finest powder, increasing the medicine's bioavailability.

If you wish to create measured doses of the powder, using a home capsule maker is the best route. Blends can also be made that incorporate additional ingredients, such as vitamin C (which enhances the medicinal potency of some species), or herbs. However, if you are cultivating your own medicinal grain spawn, an abundant supply can be readily created, making the process of encapsulating a gallon of mushroom powder a bit unnecessary. I prefer to maintain jars of individual species' powders and add these (or blends) to foods or teas as a versatile medicinal supplement. Ultimately, the hypha is the limit on how to incorporate this potent and easy to grow medicine into every facet of one's diet and lifestyle. Dig it.



Mushroom Juice

Instead of using heat, alcohol, or powdering to create medicinal mushroom products, raw mycelium and/or fruit bodies can be juiced to obtain a full-spectrum, bioactive, and potent extract. My friend James Weiser developed this process in 2013. The advantage of juicing fungi is that it does not alter the mushroom's proteins, enzymes, or volatile compounds, but creates a synergistic and holistic medicine. In anecdotal studies with a naturopath in Denver, James has seen patients suffering from Parkinson's disease dramatically improve their motor control and speaking abilities after consuming Lion's Mane juice for several months.

The easiest way to make mushroom juice is to blend fresh myceliated grain spawn in a blender or food processor. Simply mix 0.5 cups (240 mL) of grain spawn with just enough water to cover it along with a tablespoon or two of olive oil and then blend the mix until it is liquefied. Filter the mix through a finely woven muslin sack and squeeze out as much of the liquid as possible. Repeat this process one more time using the same grain spawn pulp and combine the two liquids. The leftover pulp can then be composted or calcined for its salts, which can be added to the extract. Daily doses of 1 ounce to 0.25 cups (60 mL) can be taken for up to three days. After the third day, the juice tends to loose its potency and a new batch must be made.

As this is a relatively new extraction practice, caution is advised with the consumption of mushroom juice by people with severely depressed immune systems. In a small number of cases, the consumption of raw Split Gill mushrooms (*Schizophyllum commune*) has been known to cause fungal infections in immune compromised individuals. However, to my knowledge, no similar cases have ever occurred with raw mushrooms of other species, let alone the pulverized liquid of their tissue. As with any new medicine, consuming small doses over long periods of time is a good means for gaining a familiarity with how a person will respond to mushroom juice.

The Medicine of a Liquid Culture

Some of the most potent and inexpensive medicines produced by fungi are those obtained from the pure mycelium and broth created during liquid cultivation practices. Described in depth in Chapter 8, these practices grow mycelium in a container filled with sterile water, sugar, and other nutrients. As the mycelium grows through this liquid, it exudes enzymes and medicinal sugars into the liquid medium. After a growing period of a few weeks, the mycelium can then be filtered out and processed on its own and/or the liquid broth can be processed to concentrate or extract the compounds exuded by the mycelium. This is how many of the most important fungal medicines are produced and processed in Asia and the United States. Massive metal fermentation tanks holding as much as 300,000 liters of liquid culture medium are used to cultivate a given species, or blend of species, at a time.[33] This technique is so successful that it is responsible for the production of over 10,000 tons of penicillin G each year.[34] By translating these methods to the home and community scale, many of the most potent mushroom medicines can be made for little cost and effort by Radical Mycologists around the world.

The benefits of liquid culture-based medicine production are numerous. With the mycelium grown in dispersed, small, three-dimensional clusters, the number of its active hyphal tips (where enzymes are released) is maximized, leading to an increase in the amount of enzymes per volume area when compared to a mycelial network found in solid substrates. This process is also incredibly inexpensive when compared to the techniques for growing and processing mushrooms or grain spawn. It is also quite quick, requiring only a few days or weeks to obtain large quantities of medicine, compared to the months-long process of growing some mushrooms to their fruiting stage. Yields of the major metabolites can also be quite high, with typical returns being around 50–100 milligrams per liter. In exceptional cases, the yield may be as high as one gram of a given compound per liter.

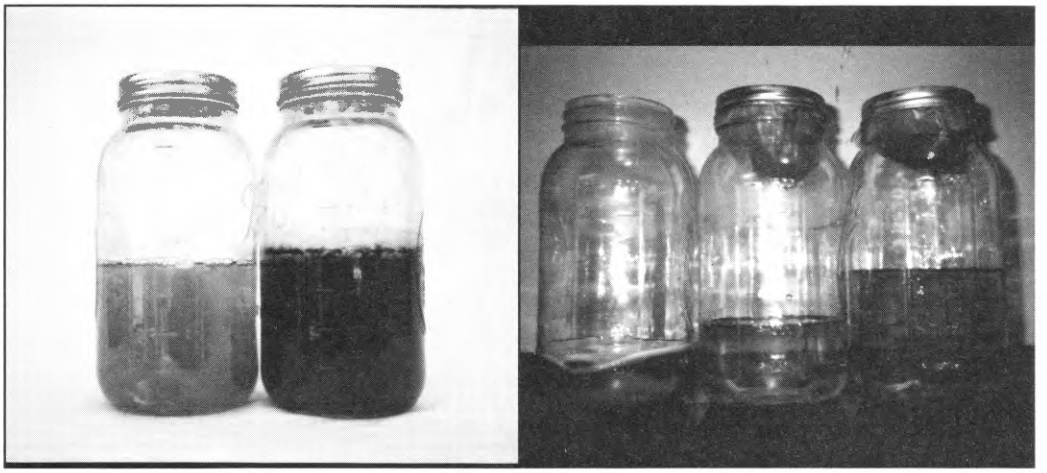
Processing a liquid culture for medicine can take one of several forms, but the liquid is usually first filtered to separate out the mycelium and process the solids and liquid products separately. In general, the compounds isolated from the mycelium tend to have a protective role for the fungus, while the extracellular metabolites isolated from the liquid are associated with the combative relationship of the organism with its environment. Notable compounds that are found in liquid culture broths include LEM, LAP, Schizophyllan, PSK, PSP, and AB-FP (from *Agaricus blazei*). The following is a basic protocol for home-scale processing of the mycelium and liquid broth fractions.

1. Filter a liquid culture broth through a double coffee filter. Try to decant as much of the liquid off as possible before dropping the mycelium into the filter. The mycelium can plug up the filter, making the filtration process quite slow. To speed things up, set up multiple filtering jars to drip.
2. Remove the mycelium from the filter and place it onto a clean piece of glass to air dry.
3. Pour the filtered liquid into the top of a double boiler and reduce the liquid to a thick, sugary paste. Or, better yet, distill the liquid under vacuum to avoid denaturing the more temperature-sensitive compounds.
4. Once the mycelium is dry, grind it to a fine powder in a mill, coffee grinder, or with a mortar and pestle. Similar to powdered grain spawn (but more concentrated), this powdered mycelium can be consumed directly, or mixed with other extracts.
5. Once the liquid is concentrated, it should be stored in a dark colored glass container. Being quite sweet, this medicine can be used to make syrups, desserts, or rolled into balls using powdered grain spawn and/or the pure mycelium from step 4 to make medicinal treats.

More advanced purification techniques can be employed to isolate specific compounds from liquid broth and mycelium for researchers doing targeted studies. In short, these methods tend to rely on purification of the fungal polysaccharides and metabolites using Soxhlet extraction, ethanol concentration, fractional precipitation, acidic precipitation with acetic acid, ion-exchange

chromatography, gel filtration, and/or affinity chromatography. These techniques are beyond the scope of this book but, once learned, can be readily translated to the above protocol by the more chemistry-oriented reader.

One consideration that should be noted for growers seeking to make the most potent liquid culture extracts is the impact that the media formula can have on the medicine production of a given species or strain. For example, different media formulas can significantly affect the structure, concentration, conformation, and molecular weight of the medicinal polysaccharides produced by a fungus. Many studies have determined the effect that pH, mineral supplementation, and the type and/or concentration of carbon and nitrogen sources will have on the compound production of medicinally important species that are commonly grown in liquid culture (e.g. Turkey Tail,[35] Cordyceps,[36] and Split Gill[37]). Lastly, to maximize antibiotic production, the growth of the fungus may need to be limited to encourage the production of these secondary metabolites. This is generally done with antibiotic-producing mold species by designing the medium so that a key nutrient becomes limited at the right time, causing a change in the fungus' metabolism and a subsequent increase in antibiotic output. For penicillin production, glucose is often the limiting factor.



(Left) These liquid cultures started out the same color. The species on the right, Pioppino (Agrocybe aegarita), produces a dark exudate that colors the liquid.

(Right) Separating the mycelium of Cordyceps sinensis from its culture broth.

Mycomeiopathics

Homeopathic remedies are energetic medicines that are created by diluting a plant or mushroom extract until none of the chemical constituents of the original extract remain. In this highly diluted form, homeopathics are said to carry the energetic signature of the original substance. Following a philosophy that "like cures like," homeopathics are used to treat symptoms that the whole substance (or its non-diluted extract) would otherwise cause in a healthy person. Water is typically the main carrier of these energetic signals, as it is said to retain a "memory" of whatever it has encountered.

While homeopathy may contradict some models of healing, it is not without empirical support. In 1988, the journal *Nature* published a study by French immunologist Jacques Benveniste that demonstrated high dilutions of certain antibodies could retain their effects on human blood cells.[38] More recently, a 2009 study by Nobel Prize winner Luc Montagnier assessed the memory of water using dilutions of water that contained specific DNA sequences. In the study, a flask of the dilution was placed next to a separate flask of pure water. To the surprise of the researchers, when DNA precursors were placed in the pure water they arranged themselves in the same sequence as the DNA that had been in the adjacent, diluted water.[39] In other words, the dilution appeared to have transmitted an information-rich signal to the second flask, a feat that Montagnier argued was due to electromagnetic signals. Along with the rich cultural history that surrounds the use of water as a carrier of intention and information, these studies help support principles that underlie homeopathy, Alchemy, and biodynamics (a topic discussed in Chapter 9).

To make a mushroom homeopathic, place the fungus' fruit body or mycelium in a glass of

pure water and set it in view of the Moon overnight. The next day, dilute the extract into 99 times its volume (i.e. place 1 mL into 99 mL, 10 mL into 990 mL, etc.) and firmly tap, or *succus*, the container one hundred times. Repeat this dilution and succussing process at least six times. The more times that the substance is diluted, the greater its potency will be. Dilutions of 6–30x are the most commonly prescribed. This liquid remedy can also be used to potentiate sugar pellets, a common carrier for homeopathics, using the same process.

MycoFormulations

The above techniques and concepts can be combined in a number of ways. For example, to make a wide-ranging medicine from a given fungal species, one route would be to reduce a mushroom tea to a thick, sugary paste, combine this paste with reduced liquid culture broth, and then mix in powdered grain spawn that has been saturated with a tincture or spagyric (discussed next) of the mushroom. This mix can then be encapsulated or rolled into balls to form measured doses. Many other variations on this concept are possible as well.

Further, different species can also be combined to produce multiple, complementary effects on the body. For example, some mushrooms only stimulate discrete aspects of the human immune system. However, a combination of these species can produce a holistic formulation that tonifies and supports the entire immune system of an individual. An example of such a blend is Shiitake, Turkey Tail, Reishi, Cordyceps, Maitake, and *Agaricus blazei*. In Tanzania, the HIV treatment Gacoca is made with a combination of Reishi, Artist's Conk, *Ganoderma pfeifferi*, Turkey Tail, *Cantharellus cibarius* and other *Cantharellus* species, Split Gill, *Phellinus ignarius*, and Amadou. As noted earlier, the addition of vitamin C has been shown to increase the efficiency of some medicinal mushroom extracts. Lastly, the potential to combine mushroom medicines with extracts from the plant and mineral kingdoms offer countless blends and botanicals that can be tailored to specific maladies or body states.

AlcheMycology: Alchemical Explorations Into the Fungal Queendom

By Jason Scott

> *Kingdom Fungi is more than a metaphor for mystery, fear, and the unknown. Similar to* Homo sapiens *searching for the philosophers stone, mushrooms and lichens recycle, transmute, and transform.*
> —ROBERT ROGERS

> *A physician without a knowledge of Astrology has no right to call himself a physician.*
> —HIPPOCRATES

Mushrooms are some of the most transformative organisms to inhabit the Earth. They are the vehicles of transmutation that subtly shift matter from their elemental form into higher states of vitality for the benefit of an ecosystem. In the fungal transformation process one finds a great power that in many ways reflects both the ancient arts of Alchemy as well as its production of potent and unique medicines. Connecting the philosophy and arts of the alchemical tradition with the healing properties of fungi provides a potent synergy between two sciences that offers wholly unexplored potentials for healing the illnesses that manifest in our body, mind, spirit, and environment. As both of these fields have been heavily marginalized throughout history, today we find a need for deep exploration and experimentation in each subject, both as individual studies as well as complementary healing modalities.

Mushrooms and other fungi provide some of Nature's most powerful medicines, and the potential for creating novel remedies and initiatic medicines through the science of Alchemy are endless.

The primary alchemical preparation is called a *spagyric*, which is produced by separating, purifying, and recombining a given material via fermentation, distillation, and calcination (incineration). Alchemists have explored spagyric preparations made with materials from the Mineral, Vegetable, and Animal realms for thousands of years; yet in all of the existing literature, the Fungal realm has been largely ignored. No traditional text or practice exists for exact protocols of preparation or use of the fungi as alchemical medicines. Thus, for this introductory piece on Alchemycology, we will propose a method for processing fungi into spagyrics and other alchemical preparations based on alchemical theory and modern pharmacology. Here we consider the fungi as occupying a realm of their own, somewhere between the vegetable and animal: the fifth and quintessential Queendom.

Before one begins preparing spagyrics, it is best to gain a foundational understanding in the history of Alchemy and to help develop a holistic understanding of the art along with its underlying philosophy, known as Hermeticism. Building from this understanding ultimately leads to the practical lab work of medicinal preparations through which these transcendental philosophies truly come to life.

Initiatic medicines are preparations that carry archetypal forces present in Nature and help a person (the initiate) to familiarize themself with those forces. Through the doctrine of signatures and correspondences it is possible to make qualitative associations which describes the archetypal force of particular organisms, in this case a fungus. Traditionally, initiates in the alchemical path would create a spagyric extract from seven different plants, each representing a planet, which would be consumed on a corresponding day of the week. It was believed this practice helped familiarize the student with the archetypes inherent in Nature and the universal cadences.

History of the Alchemical Path

Khemia—the original name for the science of Alchemy—was considered by the ancient Egyptians to be "the great art" gifted to them by Thoth, the God of language, math, and science. Thoth is also known as the Greek figure Hermes Trismegistus and it is from the teachings of Thoth/Hermes that the philosophical and spiritual cosmology known as Hermeticism arose several millennia ago. During this time, Alchemy and Hermeticism were twin studies, where each expressed a view that all of life was an emanation from one eternal source. Eventually, Alchemy spread from its home of Egypt to parts of Europe and western Asia. At its height, Alchemy was the most globally practiced system of medicine, a healing modality that embodied a philosophy that everything is connected.

The root of the word Alchemy comes from *Khem* or *Khemit*, which translates to "the black land." This was the name given to ancient Egypt by the Greeks, and referred to the fertility of the flood plains of the Nile River. When Alexander the Great conquered Egypt in 332 BCE he, along with other Greek philosophers, took a strong interest in the sacred sciences of the land, which was referred to as *Khemia.* As a part of his conquest, Alexander constructed the library of Alexandria in Egypt to preserve knowledge from all over the world, including many of the most important texts on Alchemy.

Around this time, other qualitative and holistic systems of medicine sprouted independently around the East, most notably in the Ayurvedic medicine of India and the practices of Qi-Gong and Natural Medicine in China. What is striking is that despite the geographic and cultural differences underlying the development of these practices, many commonalities can be found amongst these three traditional modalities. At their core, these traditions are all based on developing a direct relationship with Nature and reflecting that relationship through the art of healing.

In 30 BCE, the Library of Alexandria, the greatest repository of recorded knowledge in the world at the time, was burned during Roman conquest. This was the beginning of the descent of Alchemy as the Romans outlawed the art, and the bulk of alchemical knowledge was lost to the massive fire. Fearing persecution, practitioners of the art and keepers of the knowledge of Alchemy were forced to go underground. Alchemy moved East into Arabia (an area encompassed by the Iberian Peninsula, Northern Africa, the Indus Valley, and from Southern Arabia to the Caspian Sea), where it was practiced in secrecy. Alchemists were forced to practice clandestinely, only able to share their work under pseudonyms and through the employment of cryptic words and symbols.

During the 7th century Arab practitioners of the art added the prefix *"al-"* to *Khemia,* in reverence of the profit Allah. Here, many of the Alchemical writings began to take on a much more mystical and secretive tone, hiding alchemical processes under the guise of prose. By the 8th century, the Arabs had brought *Al-Khemia* back into Spain where it quickly spread into the rest of Europe and became known as Alchemy. This was not just a practice of making medicine, but an exploration into consciousness and matter, a precursor to modern Chemistry (*Chymistry*), which would later be developed in 17th century Europe.

Jabir ibn Hayyan was a famous Muslim alchemist who often used conflated language and imagery in his writings to relate alchemical processes. In Latin, Jabir translates to Geber and forms the root of our word gibberish, emphasizing the amount of seeming nonsense that was common in the alchemical texts.

Fungal Alchemical Wedding (Melanesian Myth): "When the sea had dried so that men appeared, the first two beings, after planting trees and creating food plants, made two mushrooms. The first man threw one of the mushrooms high into the sky, creating the Moon, while the first woman tossed the other mushroom upward and formed the Sun."[40]

Over time, Alchemy and its famous potential of transmuting lead into gold permeated the public consciousness. Using this idea to their own advantage, certain frauds known as *puffers* falsely claimed that by taking a bit of "seed" gold from donors they could create a vast supply of riches. Upon receiving the gold, these puffers would disappear. Such misdeeds ultimately lead to a widespread belief that alchemists were greedy or deceitful people and that the entire practice of Alchemy was not to be trusted.

By the 16th and 17th century, many scientists wanted to distance themselves from the credulous claims and activities of alchemists and their impersonators. It is from these people who abandoned the ancient knowledge that the practice of *Chymistry* and our other sciences arose. Alchemy is truly the mother of all science, preceding all of our modern practices. Modern scientists and mycologists who wish to understand the laws of Nature cannot ignore the historical significance of practical Alchemy and its accompanying philosophy.

The *Chymists* of the day were often still practicing alchemists, albeit they kept this aspect of their work private. Many famous scientists such as Paracelsus, Sir Frances Bacon, John Dee, and Isaac Newton were prominent practitioners of Alchemy. Some biographers of Newton have noted that he had committed himself to the art to such a degree that he was an alchemist and astrologer first, and a mathematician and physicist second. Newton developed the concept of gravity, Bacon was a proponent of the scientific method and credited with coming up with empiricism, and Paracelsus developed Iatro-chemistry, which has become modern pharmacology. These important discoveries still influence our model of the world today and all arose from the alchemical tradition.

In recent decades, there has been a resurgence of the term "alchemy" through new wave nuances that dismiss the importance of the practical lab work of Alchemy. The term is often applied to things that aren't actually alchemical, such as cooking processes, chocolate making, and healing "elixirs" that are not based on the practical application and traditional roots of the true practices of Alchemy. As the lost arts of Alchemy are remembered and the practices become familiar, new means are found to express the wisdom of our ancestors. Traditional practices give us new praxis to relate us back to the natural world that sustains our being. Through them, we attain tools of medicine and perception that lend radical insights into moving beyond the harmful infrastructure of the modern, industrialized, world and back into harmony with the wisdom and ways of Nature.

Hermetic Philosophy

Thoth offered the hermetic teachings to the Egyptians through the Corpus Hermeticum and the Emerald Tablets, two important texts that provide the foundation of alchemical philosophy. In essence, these writings pronounce a universal knowledge and a story of our connection to the one being which is expressed in all beings.

"As above, so below" stands as a core hermetic axiom and embodies the concept that the heavens reflect the Earth, and the Earth reflects the heavens; that the macrocosm is found in the microcosm, and vice versa; the inner world reflects the outer, and a descent into darkness is necessary to climb into the light. The processes that are carried out in the lab are a reflection of the stars in the sky; where our flask acts as a microcosm to the macrocosm of the cosmos.

Hermeticism also teaches that all things come from one thing, the *Prima Materia*, which is a web of being and spirit. The Prima Materia is the primitive, formless base of matter, akin to chaos: the primordial form of unorganized energy. When that chaos is impressed with form, life is manifest into being and expresses itself as matter. Everything is said to have both an accidental and a substantial form. The *substantial form* is what all beings strive to be, expressed as perfection and likened to gold in Alchemy. The *accidental form* is the product of environmental influences on a substantial form, and is expressed as imperfections and blemishes. The work of the alchemist is to consciously assist a being in its evolution from its accidental form to its substantial form. To transmute to its substantial form, the being must raise through vibration from the fixed to the volatile in a process of separation, purification, and cohobation. In other words, the being must die so that it may be reborn.

In preparing alchemical solutions, we follow the basic principles of Alchemy to create mushroom spagyrics that effectively purify and refine ourselves as well as the material we are working with.

This is not a one-way process, however. Through working with and raising the vibration of any

material on the physical plane, alchemists simultaneously affect their own vibration on the spiritual plane. Alchemy is a complete integration of thought and process, where the student is a reflection of the process and vice versa. The purpose of the alchemical tradition is not merely to produce medicine, but to contribute to a much more timeless work: an integration of our individual being into all things, so that we may witness our relation to the natural processes of the universe. *As you work on the work, the work works on you.*

No tree, it is said, can grow to heaven unless its roots reach down to hell.

—Carl Jung

Alchemy empowers individuals to recognize themselves within a complex and interconnected network of being and gives them access to the tools of manifestation and creation through observation. More importantly, Alchemy provides a tangible understanding of the great mysteries and a tactile practice through which to see them.

Alchemy is one of the most radical approaches we can take in reclaiming our physical and psychological sovereignty and health. The ancient art approaches illnesses by working on their root causes, whether they are physical, spiritual, or energetic. Alchemy provides insights into the patterns of Nature through direct experience and the production of potent physiospiritual medicines, contributing to a greater level of harmony within and between one's self and the environment. It is a reflective process that attunes the student to inherent patterns in Nature and how they are expressed through its material form. It offers sympathetic and antipathetic approaches to confronting disease individually, culturally, and ecologically through understanding Nature herself. It is a study of interconnection and relationship that supersedes reductionist scientific models by integrating the observation of qualitative and quantitative measures with the experience of a direct relationship with the subject.

The Doctrine of Signatures and Correspondences

The doctrine of signatures is one method by which our ancestors learned to work with natural medicine. It is based in part on the notion that by observing a plant's growth patterns and habitat, the Student can determine the energetic qualities that inform how a given plant might affect a particular individual's constitution or illness. The plant reflects the issues that it resolves. Each being is impressed with an archetypal force that gives it form and structure. By analyzing these forces, we can learn to read the energetic signatures of other beings and draw connections between shared traits.

The doctrine of signatures is based on subjective criteria in order to qualitatively understand reality. These things cannot be defended in a "court of rationality," as herbalist Matthew Wood puts it. They must be experienced. Through experiencing reality qualitatively, we form a much more intimate relationship with the natural world which helps draw archetypal correspondences.

Astrological correspondence, an extension of the doctrine of signatures, is essential to the art of Alchemy in understanding the archetypal nature of reality. Here the various planets of our solar system are found to carry energetic signatures that correspond with a particular day of the week and a particular time of the day, which is expressed in a diversity of physical forms (e.g. specific species of mushrooms, plants, animals, or minerals). Establishing correspondence thus informs how and when a given medicine should be processed, when it will be administered, and how it will affect the patient or specific disease.

When one learns to read the patterns inherent in Nature, they open themselves to understanding these energetic archetypes and can begin to engage in direct communion with the source of being by qualitatively relating to intrinsic patterns. This is the method by which the ancient alchemists came to their knowledge about their works and the natural world. Nature becomes the teacher, for no person can teach what the fungi can teach themselves.

To fully utilize the doctrine of signatures and the doctrine of correspondences, it is helpful to become familiar with the archetypal forces of Nature and how they express themselves. Listed here are a few resources that explore the planetary archetypes and how they reflect themselves in our physical reality:

- The Inner Sky – Steven Forrest
- Medical Astrology – Judith Hill
- The Master Book of Herbalism – Paul Beyerl

Planetary Correspondences

Planetary correspondences have been fairly well established for many common herbal medicines, especially in the Plant realm. Fungi, however, seem to have been significantly overlooked in this regard as no traditional correspondences for these beings can be found in ancient or modern texts. This means that modern alchemists must determine their own fungal correspondences by reading the energetic signature of a given mushroom as well as its environment.

To such as study astrology, who are the only men I know that are fit to study physick [medicine], physick without astrology being like a lamp without oil.

—Nicholas Culpepper

MycoAstrological Correspondences

Planet	Day	Main Organ	2nd Organ	System	Tissue	Action	Mushroom	Secondary Rulers
Sun	Sunday	Heart	Blood	Circulatory	Plasma	Hot/Dry	Chanterelle (*Cantharellus formosus*)	Mercury/Saturn
							King Bolete (*Boletus edulis*)	Mercury
							Reishi (*Ganoderma lucidum*)	Mercury
							Oregon Reishi (*Ganoderma oregonense*)	Mercury
							Chicken of the Woods (*Laetiporus sulphureus*)	Mars
Moon	Monday	Brain	Stomach	Nervous	Marrow	Cold/Moist	Shaggy Mane (*Coprinus comatus*)	Mars/Mercury
							Lion's Mane (*Hericium erinaceus*)	Mercury/Saturn
							Split Gill Polypore (*Schizophyllum commune*)	Mercury
							Jelly Tooth (*Pseudohydnum gelatinosum*)	Sun
							Witch's Butter (*Tremella mesenterica*)	Mercury
Mars	Tuesday	Blood	Gallbladder	Immune	Muscles/Tendons	Hot/Dry	*Cordyceps spp.*	Mercury
							Red Belted Polypore (*Fomitopsis pinicola*)	Sun
							Chaga (*Inonotus obliquus*)	Jupiter/Venus
							Birch Polypore (*Piptoporus betulinus*)	Jupiter/Saturn
							Russula integra	Sun
Mercury	Wednesday	Lungs	Mind	Respiratory	Lymph	Cold/Dry	Maitake (*Grifola frondosa*)	Jupiter/Saturn
							Pearl Oyster (*Pleurotus ostreatus*)	Moon
							Psilocybe cubensis	Saturn
							King Stropharia (*Stropharia rugosoannulata*)	Saturn
Jupiter	Thursday	Liver	Gallbladder	Metabolic	Fat	Warm/Moist	Portobello (*Agaricus bisporus*)	Saturn
							Agarikon (*Fomitopsis officinalis*)	Saturn
							Shiitake (*Lentinula edodes*)	Saturn
Venus	Friday	Kidney	Bladder	Genitourinary	Mucous	Warm/Dry	Fly Agaric (*Amanita muscaria*)	Jupiter
							Enoki (*Flammulina velutipes*)	Moon
							Artist's Conk (*Ganoderma applanatum*)	Mercury/Saturn
							Turkey Tail (*Trametes versicolor*)	Jupiter/Saturn
Saturn	Saturday	Spleen	Bone/Joint	Skeletal/Structural	Bones	Cold/Dry	Ergot (*Claviceps purpurea*) POISONOUS! NOT FOR CONSUMPTION!	Mercury
							Amadou (*Fomes fomentarius*)	Venus
							False Tinder Conk (*Phellinus igniarius*)	Moon/Jupiter

The preceeding chart lists proposed planetary correspondences for common medicinal mushrooms based on their mycelial form, fruit body stature, macroscopic features, and the medicinal actions that these species have on the human body. Through understanding mushrooms, their environment, growth patterns, physiological, emotional, and spiritual effects, one can develop their own correspondences through the archetypal framework of the planets.

We are born at a given moment in a given place and like vintage years of wine we have the qualities of the year and of the season in which we are born. Astrology does not lay claim to anything else.

—Carl Jung

Alchemycological Preps and the Spagyric Anatomy

The term "spagyric" is derived from the Greek words *"spao"* and *"agiero,"* and roughly translates as "to separate and recombine." Spagyrics are the primary form of alchemical medicine and are comprised of the three main components, or principles, of a given substance: The Salt, the Sulfur, and the Mercury. These should not be confused with the compound salt, or the elements sulfur and mercury. They are philosophical principles that describe the different levels of matter that can be obtained through the fermentation, distillation, and calcination of a substance. In alchemical work, these three principles are first separated in several steps, then they are purified to their most exalted form, and finally they are recombined in a specific fashion to produce an alchemical spagyric or other product.

There is much room for experimentation in the realm of mushrooms and their spagyric anatomy as little is known about the best practices for working with fungi alchemically. The methods offered here are meant as starting points to be explored as this area of study continues to evolve. They are based on the best practices and suggestions of various modern Alchemists and mycologists that I work with and study, including Robert Allen Bartlett, Sajah Popham, Robert Rodgers, and Peter McCoy, to name a few.

You as an apothecary and physician, you should consult your planetary influences in each patient, to regulate your prescription accordingly. In that case, I am persuaded that more immediate relief will in most cases be afforded the sick and languishing patient. Astrological science should be very useful in guiding your medical enquiries to produce the cure of overt and latent diseases.

—William Lilly

Mercury of Mushrooms

The philosophical Mercury represents the Spirit: the universal aspect of any kingdom. This is physically expressed as the volatile compounds in a substance. For the vegetable realm the universal spirit is alcohol, which is why we call drinking alcohol "spirits." The Mercury is the result of fermentation and distillation.

The spirit of any kingdom becomes a universal solvent for processing and working with other material in that same kingdom. If you are working with the vegetable realm the most common spirits are derived from grains and wine, with the grape spirit being the most effective universal agent of the vegetable realm. In processing spagyrics, it is desired to work with the spirit of your material.

Materials

- Distilled water
- Fermentation lock or a rubber hose and glass of water
- Fresh fruiting bodies or myceliated substrate
- Glass jar (fermentation vessel)
- Glass, stainless steel, or copper still

Method

1. Split the fruit bodies or myceliated substrate into two parts (by volume). Place one half into the fermentation vessel. Save the rest for obtaining the material's Sulphur.
2. Cover the material with distilled water, and cover the jar with a lid that hosts an air lock used for fermentation. Alternately, place one end of the rubber hose in a half-full glass of water (making sure that it is submerged) with the other end going through the lid of the fermentation vessel, but not into the ferment.
3. Let the jar sit for 2–4 weeks or until bubbling activity has lulled. When bubbling has ceased, it is ready for distillation.
4. Distill the mushroom wine along with the physical material in a clean distillation train. Distill the liquid at least seven times, or until a clarified spirit is retrieved.

Disclaimer

The following processes are theoretical and based off of historical practices. They are not intended to treat or cure any illness or disease and are for educational purposes only. The author of this essay does not recommend that anybody create or administer unknown and unstudied preparations to anyone. Using different extraction methods, such as unknown solvents on unstudied mushrooms, may extract harmful compounds. Be conscious of material that has not been tested. Solvents are volatile and dangerous to work with in unventilated spaces and without proper training.

Distillation Resources

Compleat Distiller – Nixon and McCaw

Home Distillation Handbook – Ola Norrman

Fermenting a grape wine with the mushroom species you are working with in place of the common brewers yeast (*Saccharomyces cerevisiae*) proposes another viable path for producing a mushroom spirit. As noted in Chapter 6, a study in Japan showed that using different genera of mushrooms produced alcohol dehydrogenase sufficient to the fermentation of wine. This leads to the implication that supplementing a wine fermentation with a desired mushroom species will attune that spirit to whatever mushroom you are working with. It also adds interesting dimensions to standard tinctures.

Sulfur of Mushrooms

The philosophical Sulfur represents the soul and the essential aspects of a being—the binding forces. It is physically represented by essential oils.

For plant works, steam distillation of fresh plant material is usually the most effective means of extracting the Sulfur. Dried plant material also works, but will usually yield less oil. The amount of oil obtained will also depend on what you are working with and what time of year you have harvested it.

Certain mushrooms have been successfully steam-distilled to retrieve oil, but the return rate is very low. For all practical purposes, mushrooms require a different level of treatment than plants to retrieve a full Sulfur extract. A polar aprotic, non-polar solvent, or potentially even an alkahest would be more effective in pulling more oil.

Steam Distillation

Materials

- Distillation train (glass, copper, or stainless steel)
  - Boiling flask
  - Chromatography flask (Biomass)
  - Hot plate
  - Liebig condenser
  - Receiving flask
  - Separatory funnel
  - Thermometer
- Distilled water
- Fresh fruiting bodies or myceliated substrate

Method

1. Fill the boiling flask with distilled water and set up the distillation train. Decide between a hydro-distillation and steam-distillation. Hydro-distillation applies more direct heat and comes from the material directly in the boiling flask. Steam-distillation comes from steam passing through material suspended in a chromatography (biomass) flask.
2. Place the fungus and/or mycelium into the distillation train for oil extraction.
3. Heat the boiling flask so that the distilled water begins to boil and pass through the system. The water will heat, move through the condenser, and coagulate in the separator funnel.
4. Release the excess water into the receiving flask and save. This is the hydrosol of the mushroom distillation.
5. If there are any oils procured through this method, they will separate from the water and either float or sink.

Solvent and Alkahest Extraction

Materials

- Solvent or alkahest
  - Acetone
  - DMSO
  - Ethanol
  - Ether
  - Methanol
  - Tartar alkahest
  - *OR* Urine alkahest
- Distillation train (optional) or evaporation dish
- Fresh or dried mushroom fruiting bodies or mycelium (one-half of starting material)
- Soxhlet extractor (optional)
- Thimble (optional)

Method

1. Fill the boiling flask of the Soxhlet extractor with the solvent or alkahest of choice.
2. Place the mushrooms being extracted into a thimble that fits the extractor. (Muslin bags work or cellulose thimbles can be purchased through science supply services).
3. Heat the boiling flask to the evaporation point of the chosen solvent. The vapors will rise through the mushroom, hit the condenser and fall back through the material and collect in a reflux side arm. Once the side arm is full, it will release the solvent back into the boiling flask to be recycled. Let this process run for a couple of hours, until the mushroom is fully extracted.
4. Strain the mushroom body and collect the solvent which now contains the essential oils (Sulfur).
5. Place the solvent into a distillation train, and gently heat the boiling flask to the evaporation temperature of the solvent. The solvent is collected in the receiving flask; the oil (Sulfur) will be left in the boiling flask.

If you do not have access to a Soxhlet extractor or distillation train, an alternative process follows:

1. Use the solvent of choice as a menstruum and cover the mushrooms with two finger widths in a glass container.
2. Let sit for at least 24 hours and filter out the body of the material.
3. Pour the solvent into an evaporation tray and put it over low heat until the solvent is completely evaporated (Make sure to do this outside or in a well-ventilated area).
4. The oil will be left in the evaporation dish. Let it sit in the open air for at least 30 days before use.

Salt of Mushrooms

The philosophical Salt represents the body, or the "fixed" aspect of the material you are working with. It symbolizes the material world and physical matter. Literally, it is the alkaline salts that are produced by calcining (burning) a substance into a fine ash and then leaching those salts from the ashes.

Mineral Salts hold a similar position to mushrooms in modern culture: they are both marginalized and not recognized for their medicinal value and constituency. Reconstituting your medicine with refined salts is one of the most integral aspects of alchemical preparation because the Salts give the Mercury and Sulfur a container, a vehicle. They also have unique medicinal properties that are often overlooked.

Materials

- Ceramic, clay, or stainless steel crucible
- Distilled water/hydrosol from oil distillation
- Evaporation dish
- Filter
- Fire source (gas or wood)
- Mortar and pestle
- Solid fungal material (Caput Mortem) left over from Mercury and Sulfur extraction

Method

1. Place the Caput Mortem (dead body of the mushroom, after the oil and spirit have been extracted) into a clean crucible.
2. Place the crucible over an open flame for calcination. Burn it wholly into a fine ash that is light grey to white in color.
3. After the body of the mushroom has been thoroughly calcined (burned), grind the ash with a mortar and pestle. The salts are now to be leached and purified.
4. Pour distilled water or mushroom hydrosol over the ash and mix into a solution.
5. Pour the mixture through a fine coffee filter into a clean container or flat dish. What is caught in the filter is discarded or used in other processes.
6. Evaporate the water off slowly, at a low heat, until the salts recrystallize in the dish.
7. Collect the recrystallized salts, and repeat steps 3–6 up to seven times, or until clean, water-soluble salt is attained.

The addition of the mineral salts to the final solution is one of the most unique aspects of the Alchemical process. The more pure and refined the salts, the higher vibration they resonate. The Salt gives a body to contain and deliver the soul and spirit to the consumer of the spagyric.

Solve Et Coagula

Volatile illnesses include a cough, fever, fiery mind, ungrounded thoughts, and anxiety. Fixed issues include kidney stones, cancer, diabetes, stagnancy, depression, and an immobile mind.

Now that the three essentials have been separated, it is time to put them back together. Each part can be combined in the proportions that they are retrieved to give a true spagyric, or the quantities can be adjusted depending on what properties are desired. If a medicine that is more volatile is sought, add more Mercury. Or if the medicine should have a more fixed quality, add more Salts. If a stronger essence is desired, implement more Sulfur. This essence can be tuned even more acutely through intentionally focusing one's will and attention on the desired use and result of the remedy. With such room for variation, the healing potential for the final product is limitless. Through understanding your material and the praxis with which to work with its parts, you can determine the most effective and beneficial preparations for a particular illness. The spiritual and physical being of the mushroom, once combined, becomes a dynamic medicine for mind, body, and spirit.

Ens Tincture

The Ens tincture is an intriguing preparation using purified salts from the ash of fire imbibed with moisture from the atmosphere. It is thought to contain "Celestial Fire," or divine spiritual energy. This process provides you with a unique menstruum that is alkaline in nature and is the starting point for creating an Ens. The first extraction produced with this method is referred to as the Primum Ens and is said to exalt the medicinal properties of the mushroom or plant that is being worked with.

Materials

- Fresh mushroom fruiting body or mycelium
- Glass dish
- Glass jar
- High (190) proof ethanol
- Potassium carbonate (K_2CO_3)
- Syringe

Method

1. To begin, the potassium carbonate needs to be left in a dish open to the air so that it can deliquesce. Once it has liquefied, it has become the Oil of Tartar, our starting menstruum.
2. Place freshly harvested fruiting bodies or mycelium directly into a glass jar filled with the Oil of Tartar so that the liquid is covering the material. If the mushroom is floating, use plastic or glass to weigh it down in the jar.
3. Let the solution sit for at least 24 hours so that the Oil of Tartar can extract the mushroom.
4. Without disturbing the solution, float dry alcohol on the surface of the Oil of Tartar. Do this by gently pouring alcohol down the side of the container. If there is any water in the alcohol it will take up the potassium carbonate, which will make the final product bitter.
5. Leave the alcohol on top of the solution for at least 12 hours. It will begin to take on a light color.
6. At this point, remove the layer of alcohol with a syringe and place it into a different container.

What you have left in the alcohol is an Ens tincture, which can be diluted with distilled water and ingested for the physical and metaphysical properties of the material you are working with. The Ens process will give you the Quintessence of your starting material, exalting its physiological, emotional, and spiritual influence. You can also choose to evaporate the alcohol, which will leave you with a crystallized Primum Ens. This is a powerful extraction method; be careful.

Alchemycology

Alchemy is the art of transmutation, and there are few agents of transmutation that compare to mushrooms. Their ecological function and interactions embody the alchemical process and its three principles. The parallels between alchemy and mushrooms are innumerable, and in many ways the philosophy of alchemy encompasses—and can be encompassed by—all of life.

Fungi embody the essence of the Salt in the act of mycoremediation. Here the body of the mushroom integrates into the body of the Earth to fortify weakness, build networks, cleanse the environment, and transmute toxic materials and systems. Mycoremediation is the most physical aspect of fungal relationships and produces tangible results that can be recorded, showing changes in the toxicity of the environment.

The Sulfur is embodied through the reproduction and growth of mycelial networks. As fungi grow and develop into their environment, they experience and adapt to new food sources, disassembling substrates into their elements for assimilation, transmuting matter into life. This process informs the individual essence of the mushroom as it expresses itself through the environment to perform ecological functions and produce medicinal compounds that make each mushroom unique.

The Mercury of the mushroom is expressed through communication with its environment and within our own consciousness by our interactions with fungi. It represents the universal aspect, or spirit, of mycological intelligence. This is most profoundly experienced through psychoactive fungi and requires no physical processing. In a sense, that mushroom is its own Quintessence, a being whole in and of itself, needing little to no purification. Though most people probably experience this aspect through the former expression, mushrooms are communicating all of the time through ecosystems and between the organisms that they contain.

Working with different mushrooms in their natural environments and through the alchemical processes offers a variety of deeper insights into their properties and purpose. Mushrooms exist independently of our consciousness and fulfill their own biological and ecological function. Exploring the mycological realm through direct observation can lend great insight into harmoniously living with our environment: it is a way to respect mushrooms as living and intelligent beings, and to see Nature as a living and intelligent system of interdependent networks. Everything exists in relationship to everything else.

Exploring mycology through the lens of the alchemist can lend unprecedented insight into both of these maligned and obscured fields of study, illuminating pathways to creating potent and effective medicines as well as deeper perspectives into natural patterns and relationships. As we come to understand the transformational powers of mushrooms, we find that they can be employed to transmute the toxic environments in our bodies and ecosystems through a conscious evolution to develop a more harmonious form of being.

Part IV

Collaboration

Chapter Eight

Working With Fungi

When people try to grow crops using human knowledge, they will never be anything more than farmers. If they can look at things with an empty mind as a child does, then, through the crops and their own labor, they will be able to gaze into the entire universe. —Masanobu Fukuoka[1]

Radical Mycologists live in a unique era of fungal cultivation. With the advancements in understanding of fungal biology and ecology over the last century, working with fungi in the lab, kitchen, garden, or woods has become more accessible than ever before. No longer must mushroom cultivation be reserved for the few that can afford it. And no longer should it be presented as something that only "professionals" can do. Radical mushroom cultivation is an act of liberation, a proclamation that one can master something long considered next to impossible. It is a life enhancing skill that can be practiced under a range of conditions, budgets, and climates to create food, medicine, soil, building materials, and new perspectives on how to live one's life. The growth of fungi is a mesmerizing process, a mediation on the great Fungal Way that constantly calls the cultivator back to the message of the mycelium and the world it binds. For communities, the appropriate applications of fungal cultivation have only begun to be explored, leaving Radical Mycologists with the opportunity to actively expand and refine human-fungal-ecological intersections and heal the lands and lives of their bioregion. Perhaps not surprisingly, this skillset is being freed during an era in which it is most needed.

The moment the cultivator embraces their work's unknown potential, the practice of cultivation transitions from a science to an art. Through continuous, hands-on experience, one's skill and relationship with fungi grows, along with their sense of intuition and creativity. In time, all practitioners develop a unique approach to working with fungi—a rhythmic and undemanding act that fills their niche and needs. Ultimately, working with fungi is simple and natural in its most basic forms. It is in mapping its limits that one finds the greatest challenge.

Mushroom Cultivation: A Play in Four Acts

At its core, mushroom growing is the process of feeding a mycelial network a proper diet, keeping it protected from competition until it has grown to a substantial size, and then triggering that mycelium to produce fruit bodies. For indoor cultivation, there are four key stages to this process:

1. Spores or a small amount of mycelium is introduced to either a petri dish containing a layer of sterile, nutrified gel or to a jar filled with sterile, nutrified water. Over the course of 7–21 days, a mycelial network will begin to exponentially increase in size inside of the container, covering or filling it. Once this network is large enough for the cultivator to easily interact with, the mycelium is broken up to become *inoculum*.

2. A small amount of agar-based or liquid inoculum is transferred to a container filled with cooked and sterilized grains. Within 2–4 weeks, the mycelium will grow over and through these grains to create *grain spawn*.
3. Healthy grain spawn is used to inoculate a final *fruiting substrate* that will support a large crop. Common substrates include wood, straw, coffee grounds, manure, and/or compost-based substrates. Two weeks to three months later, the substrate will be fully myceliated.
4. Once this final substrate is fully consumed by the fungus, the mycelial mass is moved into a humid environment to support the full development of mushrooms. The first crop, or *flush*, is often produced within 1–2 weeks. With proper care, several subsequent flushes may develop over the proceeding weeks and months. Once the mycelium stops producing mushrooms, the "spent" spawn may be applied in a variety of ways.

In essence, this process has two broad divisions: Stages 1–3 focus on mycelial/vegetative growth (a.k.a. *spawn* production), while Stage 4 is dedicated to the reproductive/fruiting aspect of the mushroom lifecycle. These two divisions and their various iterations are the focus of this chapter. In the next two chapters we will see how the mycelium cultivated in Stage 3 can be applied in a variety of outdoor practices that transcend the limitations of indoor fruiting strategies. If outdoor work is more appealing to you, I recommend gaining a basic understanding of the indoor methodology as the principles and practices that guide its design directly influence naturalized techniques.

The Species We Grow

Of the 3,000 mushrooms species that can be considered prime edibles, only about 200 have been experimentally grown, and around 60 species are commercially cultivated for food and/or medicine. Approximately 30 have been selected as ideal species, largely due to their edibility, taste, ease of cultivation, and/or shelf life. Only six are cultivated on an industrial scale. Eighty-five percent of global mushroom cultivation is dominated by these six species, which include the Button mushroom (*Agaricus bisporus*, 31.8%), Shiitake (25.4%), *Pleurotus spp.* (14.2%), *Auricularia spp.* (7.90%), Enoki (4.60%), and the Paddy Straw mushroom (3.0%).

Of these few species, the majority are primary decomposer Basidiomycetes that prefer wood-based substrates (the wood-lovers). A smaller number are later stage decomposers that prefer partially digested material, such as compost (the compost-lovers). Some species, such as the King Stropharia, blur the line between niches by being able to consume both fresh and aged substrates. The only Ascomycete mushrooms that are commonly cultivated in the West are Morels (*Morchella spp.*).

It is important to note that the skills presented in this and the following chapter can also be applied to cultivate the vast majority of the world's decomposing fungi. While historically the emphasis has been constricted to just a few species, the future of mycology will undoubtedly lead to the cultivation and integration of many genera and species that have not yet been fully appreciated for their human and ecological value.

Fungamental Principles and Patterns of Mushroom Cultivation

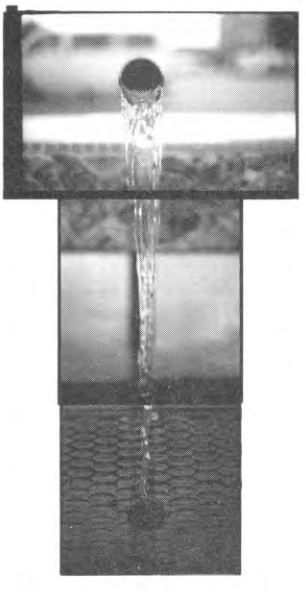
It is estimated that only 5% of environmental fungi can be cultivated.[2]

As one gains experience with the techniques presented in this chapter, a sense often arises that below the rationale given for the various protocols, there is another, subtler set of rules governing the art. Following years of comparing my cultivation experiences and insights with those of other cultivators, I have come to distill what I find to be the 15 principles that govern the entire process. Whereas the protocols of cultivation are the spurious eruptions of fruit bodies across a field, these patterns are the mycelium that holds their scattered motions together.

Understanding these principles has changed how I engage with fungi and envision my cultivation potential. With them in mind, I am no longer constricted to trying to understand *how* someone else's process is done. Instead, my thinking now focuses on asking *why* any project does or doesn't work, often to find the answer reflected in the following principles. These few core concepts run through this and the next two chapters, guiding both the growth of the mycelium as well as the hands that build their substrate.

The Five Fungal Needs

Fungi Need Lots of Good Water, but Not Too Much



The growth of mycelium is powered by water. So critical is water to successful cultivation that its presence should be seen as one of the greatest limiting factors to the growth of any operation. While there are many ways to cultivate fungi, all require this magic molecule of life.

Thus, the substrates we use should be hydrated to their maximum water-holding state, a state known as *field capacity*. This hydration level looks and feels different for each of the materials commonly used in cultivation. But for all of them, the goal is to get the material as wet as possible without creating a product that is "muddy" or that pools nutrient-rich water in the bottom of its container. An anaerobic pool of water is unwanted in any cultivation stage as it simultaneously prohibits the growth of the oxygen-dependent mushroom mycelium, while also serving as a breeding ground for competitors. Thus, it is better to err on the side of making substrates too dry rather than too wet. Most experienced cultivators can tell when a substrate is properly hydrated by giving it a quick "feel test:" a couple squeezes with the hand and a moment of intuition with the gut. Once the substrate is inoculated, it is placed in a container that will minimize dehydration.

The water that is used for all of our work should be of the highest quality possible. Most of the chemicals that are commonly added to municipal water supplies are harmful to mycelial growth. Water treated with chlorine gas can be left standing in open containers for 24 hours to allow the dissolved gas to evaporate. For more persistent chlorine compounds, vitamin C (as ascorbic acid) can be added at the same molar concentration as the compound.[3] The highest quality water for mushroom cultivation is that which has been not been run through the unnatural linear flow of pipes. Springs, clean ponds, and artesian wells are all ideal water sources. That said, many cultivators without access to these sources have good success using their tap water directly.

Fungi Need a Healthy Diet

As with all other living organisms, fungi have distinct nutritional requirements that must be properly balanced to ensure their optimal growth. Often, the best diet for a fungus is one that reflects its natural habitat. Primary decomposers (wood-lovers) such as Shiitake, Reishi, and Lion's Mane all prefer fresh wood-based substrates, while *Agaricus* species and other late-stage decomposers fruit best off of thoroughly composted materials. In between these two groups we find King Stropharia, Shaggy Manes, and various *Psilocybe* species that fruit well on a range of fresh to partially decomposed materials. Finally, the duff-dwelling Blewits, Shaggy Parasols, and Morels have been shown to grow the best in soil- and humus-based substrates where microbial interactions are high and nutrients are more dispersed. Curiously, the lines between all of these groups often blur as strains of each species can vary widely in their nutritional requirements and preferred fruiting substrate, and many can be acclimated to digest uncommon substrates. Learning to match the picky eating habits of a given species/strain is one of the keys to obtaining consistently high yields.

Fungi Need to Breathe

At all stages of the cultivation process, oxygen must be provided to the fungus so that it can breathe and grow. The level of oxygen provided depends on the stage of cultivation. During stages 1–3, low oxygen/high CO_2 levels are called for to mimic the air quality found in the soils and dense wood pieces that fungi naturally inhabit during their vegetative state. For the cultivator, this means ensuring that any container used for spawn production has holes that allow for passive air exchange

and that is also not too large in any given dimension. If a substrate is too dense, anaerobic rotting can occur in the oxygen-deprived core of the material and negatively affect the fungus' growth. Airflow should always be provided to some degree as stagnant air encourages the growth of contaminant molds. When mushrooms begin to arise from a mycelial network, these gas levels are reversed, mimicking the fungus' natural exit from their substrate's interior into the oxygen-rich external world.

Fungi Need Warmth

Most mushrooms are mesophilic, meaning that they grow best in about the same temperatures that humans prefer. The mushrooms we grow can tolerate a range of temperatures, but most grow best around 70°F (21°C). As temperatures get colder, metabolism and growth rates dramatically decrease, providing an increased window of opportunity for competitors to gain a foothold on a substrate. For most species, growth rates double with every increase in 10°C. However, temperatures that are above 105°F (40°C) will kill most mushroom species. Depending on the species, the ambient temperature may need to be raised or dropped to initiate fruiting.

Mushrooms Need a Proper Fruiting Surface

While mycelium can be grown in any shape, high quality mushroom development is dependent on the structure and orientation of the fruiting surface. For example, some species grow best horizontally off of the sides of logs, tree stumps, bags, and buckets, while others prefer to fruit vertically from the ground or top surfaces of substrates. This preference directly influences the choice of container from which a species is fruited indoors and the design of an outdoor installation.

The Ten Time-Tested Truisms

Strains Matter

Every unique combination of two monokaryotic mycelial networks is referred to as a strain. And just as every human, snowflake, or variety of corn has its own appearance and habits, so does every mushroom strain differ in its ease of cultivation, medicinal potency, remediative capacity, and flavor profile. For this reason, cultivators cherish strains that are known to grow rapidly and/or produce high quality yields. To fulfill the demand for high quality cultures, commercial culture libraries sell rare or high quality strains at incredibly high prices ($20-$1000!), making these companies the key holders to success in the eyes of many cultivators.

This emphasis on commercial cultures has largely overlooked the benefits of working with strains that are found in the cultivator's local environment. For example, imported strains may have finicky fruiting requirements, while local strains are often more tolerant of local weather conditions. Wild harvested strains also tend to be more resilient to stress and local contaminants, reflecting a rugged life history free of sterile environments. In general, the most resilient cultivation strategies work with local or developed strains that prefer the local climate or available substrates, thus avoiding the cost and unknown history of commercial cultures.

A plant analogy to mushroom strains is found with apple varietals. Apple seeds have a 1:10,000 chance of producing the same variety of apple that they came from. This is why most orchardists graft trees. In the same way, the average cultivator prefers to work with strains of known quality, rather than germinating spores and creating new strains with unknown traits.

Fungi are Energy-Conserving and Self-Preserving

Though cultivators often think they are controlling the fungus that they work with, it is really the mycelial networks that determine how successful and long-lived a given project will be. As free and wild creatures, fungi only perform the work that benefits them and their immediate environment most directly. Of the countless antimicrobial and digestive enzymes that a fungus can release, it only expends its internal resources on producing those enzymes that are necessary for its immediate survival.

In natural systems, fungi produce an array of these compounds to defend themselves and their substrates from a dynamic and constantly changing universe of competitors. But in the artificial, sterile conditions of indoor cultivation, the absence of competitive microbes causes a mycelial network to cease production of its defensive compounds. In the short term, this allows the fungus

to conserve its energy by letting down its guard, enabling it to focus on eating and growing. The problem, though, is that the fungus is thereafter much more susceptible to attack by competitors, leading to increased rates of contamination with cultures that have spent a long time under aseptic conditions. Ironically, sterile cultivation creates the need for greater sterility.

When a mycelial network is fed the same substrate for an extended period of time, it may stop producing the enzymes required for digesting another substance. If the fungus' diet is constricted for too long, this lack of variation in its environment can also cause the mycelium to slow in its growth. This slowing of a culture is commonly referred to as *senescence* and has historically been attributed by a small number of mycologists to the aging of the mycelium, a theory that is unreflective of the fact that wild mycelial networks can survive for thousands of years. Rather than dying out, most mycologists agree that sterile mycelial cultures senesce because they shut down various metabolic pathways in reflection of the absence of novelty and external stimuli. In other words, the mycelium gets bored and loses its will to live.

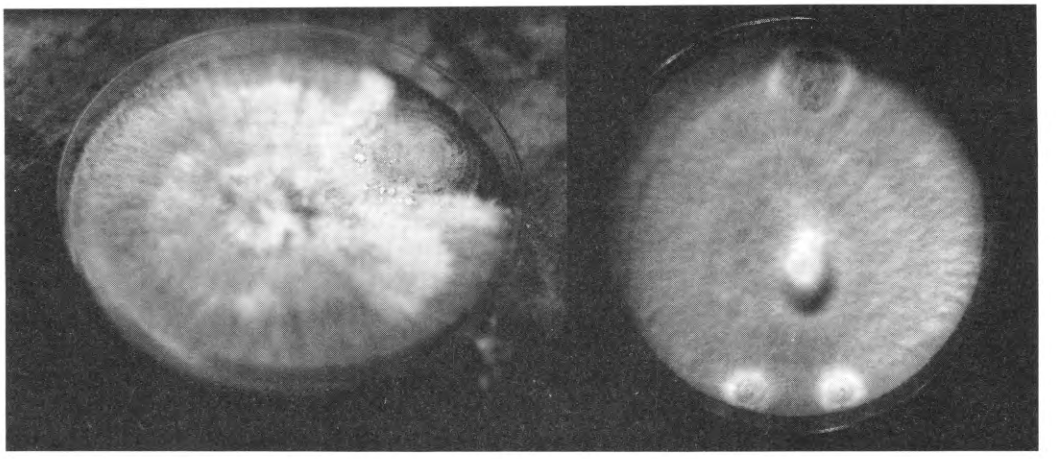
Vigor is Variable

To minimize the effects of senescence, mycelium should be grown in a variety of environments throughout its life in cultivation. The simplest way to do this is to provide the fungus with a dynamic diet. Every time mycelium is transferred to a new substrate, the formula of the new media should be different from the last one used and should ideally contain multiple ingredients. This constant variety of substrates forces the fungus to stay on its toes and constantly change its response to its environment. This range of foodstuffs also keeps the fungus happy. Do you like eating the same thing all of the time?

Senescence can potentially be reversed if a mycelial network is sufficiently stimulated into turning on dormant genes. The introduction of competitor microbes via the use of pasteurized substrates or the installation of the fungus outdoors are two examples of such stimulation. These competitive environments force the fungus to defend itself or die. If the mycelium has been in sterile culture for too long, it may not be able to defend itself and could fall victim to competitors. But if the fungus establishes in these more challenging environments, the aggressiveness of the mycelium will increase, allowing a cultivator to reculture its tissue and place it back into aseptic practices where it will grow with renewed vigor. Senesced cultures can sometimes be reinvigorated simply through the agitation that comes with liquid inoculum practices. Reinvigoration does not always work, especially with species that are generally less vigorous to begin with, but it is worth a try if you are at risk of losing a strain to senescence.

Fungi Adapt to Their Environment

Along with the introduction of competitor microbes to elicit metabolite production (as discussed in Chapter 7), cultivators can guide fungi toward greater resilience by helping the fungus acclimate to a new substrate or environment. Upon contact with a novel substrate, fungi often go into a period of stasis in which their growth halts as the fungus scans its DNA to determine which genes will produce the proper enzyme(s) needed to digest the new food source. It is akin to the fungus finding the right key on a key ring to unlock a treasure box, and then mass-producing that key to open all the treasure boxes in the area. This learning process is often seen in petri dishes when a mushroom mycelial network encounters a mold or bacteria, stalls in its growth, and a few days later begins producing a liquid exudate of antibiotics as it starts to grow over the competitor. Constant use of this adaptive capacity is how the fungi have been able to proliferate around the world with such phenomenal success. Advanced cultivation strategies account for this ability by acclimating fungi to particular microbes for the production of novel antibiotics, or to toxic chemicals to produce strains that can readily degrade a particular pollutant.



(Left) A common epigentic response to competitive microbes. At the leading edge, potent antibiotic compounds are exuded to resist attack from the advancing Trichoderma *mold.*

(Right) After the appropriate compound is determined, the fungus overgrows the mold and increases in vigor.

Fungi Respond Well to Incremental Stress

Though fungi can tolerate significant shifts in their environment, most species can only handle one or two major changes at a time. If too many factors change at once, the fungus may become overwhelmed, halting mycelial growth. Though the fungus may recuperate, during this stagnancy period its resources are focused so heavily on recovering from the shock that it has little energy for defense, leaving it highly vulnerable to attack by competitors. My friend James Weiser once summarized the three main changes that a fungus can tolerate as *new substrates, new competitors,* and *habitat disturbances* (such as the breaking of a mycelial network during transfers). While most species can handle one or two of these shifts at a time, the combined stress of all three influences tends to result in the cessation of the fungus' growth.

Fungi are Defensive but Competition Should Be Minimized

Though most mushrooms can defend themselves against competitive microbes, for practical purposes, the indoor cultivator should work to minimize this stressor. The less energy the fungus expends on defending itself, the more it has to put toward producing large flushes of fruit bodies. For this reason, substrates are pasteurized, sterilized, or otherwise cleaned, while transfers are done under *aseptic* conditions.

Culture from the Leading Edge

As detailed in Chapter 1, the majority of the fungus' growth, digestion, environmental assessment, and absorption occurs at the tips of each hypha. At the leading edge of the culture, growth is the most explosive. As a network ages, the interior mycelium eventually gets cut off from the nutrient flow of the system, resulting in minimal metabolic activity in this inner tissue. To harness a fungus' metabolic maximum, mycelial transfers should include a section of a culture's edge, if possible.

Mycelium is a Hologram

If a mycelial network is placed in a dynamic environment without physical boundaries and unlimited food supplies, it will grow indefinitely. If the fungus ever runs out of substrate or encounters a physical barrier, its vegetative growth will cease and its energy will shift toward fruit body production. For the cultivator, this means that if a fungus overgrows its container, or if conditions are otherwise not conductive to fruiting, it will become stunted in its growth and less vigorous in subsequent stages of cultivation. To avoid mycelial constriction and promote its endless regeneration, it is best to always perform transfers as soon as the mycelium has consumed its substrate and/or before it hits a growth boundary. When to do this depends on the substrate being used.

The Fungi Will Teach You More Than Any Person

The limits of appropriately applied mushroom cultivation are unknown. Where its history has for so long been constricted, the cultivators of today should seek to push the current boundaries of fungal cultivation into new fields of research. I cannot overstate the importance of trying new things when working with fungi, nor can I summarize the great value of learning from mistakes and experimenting. Many of the techniques and insights presented in the following pages are based on the direct experiences of many cultivators who intentionally did things that were not supposed to work. Every time knowledge is gained on how fungi respond to novel conditions or ecologically reflective designs, the skill of the cultivator and the depth of dialogue surrounding cultivation advances one step forward. Without experimentation, we will never fully understand what the possibilities are for working with fungi. Indeed, many of the greatest advances in science have arisen due to accident and/or intuition. If we only repeat what others tell us to believe about the fungi, we deny our ability to form our own relationships with them. It is by slowing down and paying attention to the responses of fungi that we learn most directly from them, enabling the chance to uncover an understanding of their ways that no book could ever teach.

Mushroom Cultivation is Simple and Scalable

The entire process of mushroom cultivation reflects the holographic nature of mycelial growth, from the microcosm of gestation to the macrocosm of expansion and movement. The cultivation process itself is nothing more than an exponential proliferation of a mycelial network from one container to many and from one substrate to another. Each of the practices outlined below can be done in a small kitchen or in a large warehouse. The scale of a project is solely dependent on supplying the tools and infrastructure that will adequately address the underlying principles of the processes involved. Mushroom cultivation is not a very difficult skill to master once a sound understanding of the rationale behind its methodologies is fully grasped.

When a cultivator allows these principles to direct their practice, the question of whether a novel experiment will work is somewhat unnecessary. If an experiment does not fully account for the above constraints, it is likely to fail. If the project's design matches the above criteria and reflects these patterns of the fungi, success is almost guaranteed. And it is from their dissemination that ever more appropriate innovations will be developed to demonstrate how fungi can address an array of social and environmental issues in the present and not too distant future.

I recommend revisiting the above concepts from time to time as you progress through your cultivation trials. I anticipate that eventually these principles will no longer be seen merely as rules to memorize but as reflections of your personal experiences in working with fungi. Such an integration of these concepts speaks to the strength of a cultivator's relationship with the Queendom and is the mark of a true adept.

Working With Contaminants *(or, Why We Do Much of What We Do)*

Before exploring this chapter's protocols, one of the greatest influences on all cultivation designs and outcomes must be discussed in depth: competition from other microbes. The growth of unexpected molds, yeasts, and bacteria is a common experience in mushroom cultivation due to the fact that the sugary, nutrient-rich, and moist substrates used are ideal for these competitors. When competitors begin to grow on a substrate, they often grow faster than the mushroom mycelium, leading to the contamination of substrates. Once contaminated, these substrates are no longer suitable for normal cultivation practices. The most commonly encountered indoor competitors include:

- **Molds:** Innumerable mold spores fill the air we breathe. There is no escaping these pernicious and ubiquitous opportunists, making their potential to appear at any stage of the cultivation process unavoidable. The most common fungal competitors that every cultivator will invariably come to know and love to hate include the black *Mucor* pin molds, blue-green *Penicillium*, and infamous olive-green *Trichoderma* species.

Trichoderma species are mycoparasites that are often found growing directly on the mushroom mycelium as opposed to the actual substrate. They produce toxins such as trichothecin and the sesquiterpene trichodermin to antagonize other fungi. The proliferation of molds can indicate senescence in the mushroom or low airflow.

- **Bacteria and yeasts:** A wide variety of bacteria and yeasts can present on agar as slimy streaks or clusters. The coloration of these microorganism colonies may be yellow, brown, pink, gray, or translucent. Grain spawn contaminated by bacteria often appears as a "wet spot" of non-myceliated, greasy substrate, and tends to impart a foul odor. Liquid inoculum contaminated with these microbes is often cloudy, discolored, and/or translucent. Fruiting bodies infected by bacteria will present with lesions or abnormalities. Some bacteria (most notably *Bacillus cereus* and other *Bacillus* species) can go into a state of suspended animation and form a heat-resistant "shield" known as an *endospore* that can withstand boiling temperatures. For this reason, grains are soaked overnight to awaken these bacteria from dormancy and make them susceptible to the high temperatures of the sterilization process.
- **Viruses:** Viruses are not possible to detect with the naked eye. However, viral infections can be seen in the form of fruit body deformations.

The Eight Causes of Contamination

To reduce the presence of the above competitors, it is important to understand how they develop on substrates. Microorganisms cover the surface of all objects and permeate all porous materials. This fact should be held in mind for all cultivation practices by assuming that microbes are everywhere, regardless of one's cleanliness regimen. This hyper-awareness encourages habits that minimize the movement of microbes from the surrounding environment into the sterile interior of a substrate container, where they are not desired.

The Cultivator

Our body is an ecosystem of microbes that creates a thick coating of bacteria and yeasts on our skin and clothing. The cultivator is perhaps the primary vector of competitors in the whole cultivation process. As such, the cultivator should ideally be freshly bathed and wearing freshly washed clothing. Shoes should be removed or covered in a protective sock before entering the transfer workspace. Some cultivators even wear a hairnet, facemask, arm sleeves, and/or latex gloves during transfers. During transfer work, the cultivator should not talk or open their mouth as contaminants may be sprayed from their mouth into the substrate container.

The Air

To reduce the presence of competitors that naturally fill the air, most work is done in an aseptic transfer space, described below. The air surrounding this transfer space should be cleaned prior to work using one of the following methods:

- Spray the air of the environment with 70–80% alcohol, 10% bleach, or a commercial disinfectant 3–5 minutes prior to working. This spray will not only help kill ambient microbes but will also "trap" and pull them down out of the air as the mist sinks. Take care not to inhale these sprays.
- Pump air into the workspace through a high efficiency particulate air (HEPA) filter system. This will create a positive pressure in the work area that pushes dirty air out of the environment.

The Environment

Work spaces should lack carpeting, be easy to clean, and cleared of all sources of mold, mildew, rodent infestation, or any other dirty elements. Walls should be painted with an easy to clean latex paint and the floor made of cement and/or equipped with a floor drain to facilitate cleaning. Work

tables and shelving of non-porous metal or plastic that are easy to sanitize are preferred over wooden infrastructure. In the fruiting space, pockets of stagnant air should be eliminated as this encourages mold growth. All walls and surfaces in the workspaces should be regularly cleaned with disinfectants. Workspaces may also have an anti-chamber where shoes are removed and drafts from the outside environment are reduced. For smaller operations, a small transfer room can be constructed with wooden framing and plastic sheeting.

The Substrate

Most substrates are treated to kill any unwanted microbes living on or within them. These techniques are discussed later.

The Inoculum

The spores or mycelium you work with as inoculum can be a source of outside contamination. Cloned wild mushrooms often produce bacterial colonies on agar plates due to the presence of beneficial or benign bacteria living in the mushroom tissue. Sterile mycelium that was transferred and/or stored improperly can also harbor contaminants. Spore prints often harbor competitor spores or bacteria due to the difficultly in obtaining 100% pure spore prints.

The Tools

Despite your best efforts to maintain sterility, all tools and vessel surfaces must be considered covered in contaminants. Tools should be sterilized along with substrates prior to use as well as in between each transfer by using a heat source.

Pests

Fungal gnats and other insects are a major problem in fruiting spaces. These pests not only eat mushrooms and mycelium, they also spread contaminants between mushrooms and their mycelium.

Technique

The use of conscientious, quick, controlled movements during mycelium transfers is essential for achieving low contamination rates. During every transfer, a keen awareness should be given to the location of one's hands and tools. These should never pass over the opening of a sterile vessel or over exposed mycelium unnecessarily as microbes could potentially fall off of these objects and into the substrate container, leading to contamination. If a tool touches any surface by accident, it should be resterilized with a heat source. Containers should be opened for the shortest amount of time and with the smallest opening possible, and mycelium should be transferred quickly. The more time a transfer takes and the wider a plate or jar lid is opened to the surrounding environment, the higher the risk of contamination.

The beginner, prone to making simple mistakes, is often uncomfortable and shaky with tools and/or unconscious of the placement of their hands. But, as one gains experience, a refined, graceful technique becomes second nature. In my experience, a deft and quick mycelial transfer methodology is the most important factor in the success of aseptic work. Should contamination rates remain high after all other sources of contamination have been dealt with, the technique of the cultivator must be thoroughly reviewed for error.

The above practices are advised for mushroom farms and larger operations where every contaminated grain jar or spawn bag equates to an economic loss. However, for the home cultivator I find that several of the above practices are unnecessary. The vast majority of my indoor cultivation has been a far cry from what most cultivators claim is required for success. I never bathe or change my clothes prior to work; often I'm wearing a relatively dirty flannel shirt or jacket. I have done successful transfer work in moldy basements, dusty sheds, carpeted bedrooms, outdoors, and in an RV driving down the freeway. And yet, I consistently get very low rates of contamination even when working with agar. I attribute my success to the fact that I focus solely on the immediate, one

square foot area where the transfers are occurring. I keep this transfer space clean, my tools are frequently resterilized, and my technique is quick and cautious. When transfers are done in this way, my success remains high.

Once a container is inoculated and closed, the cleanliness of the incubation space is almost arbitrary as the container is sealed off from the external environment (apart from an air filter). Though bugs and other pests should be minimized in the fruiting room, molds and bacteria are less of a concern at this stage as substrates are covered in the protective (and hopefully healthy and defensive) mushroom mycelium. I find cleanliness of the greatest importance in the transfer space and secondly in the fruiting space. Developing a keen awareness of the causes of contamination is central to developing a personal protocol for success. However, for smaller operations I do not find it necessary to loose sleep and invest large amounts of money in an endless effort to create an impeccably clean and unnatural mushroom cultivation practice.

Dealing with Competitors

The inevitability of contamination is a fact that every cultivator must embrace before beginning. In these moments, there are a number of ways to remove competitors and attempt a substrate rescue.

Molds

As molds prefer acidic environments, many of these competitors can be combated with the application of a pH increasing substance, such as baking soda. Other molds can be killed by being exposed to red light or sunlight for a few hours. For spawn bags contaminated with *Trichoderma* molds, 27% hydrogen peroxide can be injected above the contamination zone with a syringe and needle to work as an effective fungicide that does not kill the mushroom mycelium. Biodynamic preparation 508 (covered in Chapter 9) can also be sprayed on affected areas. If the infection is severe, apply 508 for three consecutive nights. Many spoilage fungi can also be inhibited by the directed application of pulsed light and/or electric fields.[4]

Pests

Indoor pests are best avoided through preventative measures. Maintaining a clean building and moving compost piles or other food waste sources as far from the fruiting space as possible are the first steps in dealing with these vectors of contamination. Fly tape and pet tree frogs can be intentionally introduced to the fruiting space to reduce insect populations. A cup of beer, wine, or vinegar covered with aluminum foil that has a few holes poked in it will attract and trap bugs. The organic pesticide Gnatrol™ uses the bacteria *Bacillus thuringiensis* to kill gnat larvae. Suspending a plastic bag filled with water and several pennies above a doorway is a traditional practice for deterring flies. A variety of homemade bug repellent recipes can be found online.

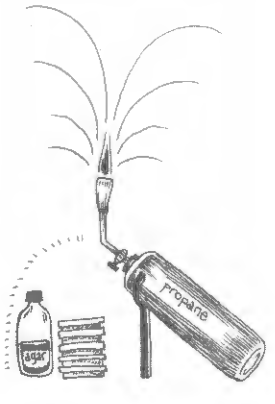
Bacterial and viral infections cannot be readily treated once they have taken over a large amount of substrate. For large operations, cleanliness should be emphasized as best as possible. In the event of a major contaminant outbreak, all equipment, walls, and surfaces should be washed and sanitized with a strong disinfectant. This is not a pleasant process. Stay vigilant!

Work Spaces

At the minimum, a typical aseptic mushroom operation requires three designated areas for the major stages of cultivation: a clean area where mycelium is transferred, an incubation area where the fungi myceliate their substrates, and a humid environment for fruiting mushrooms. The size and proximity of these spaces is dependent on the requirements and limitations of a given project, its location, and the relationship of these spaces to each other. Large farms designate discrete rooms for each work area while many home cultivators place all of these spaces together in a garage, shed, or large closet.

As with any trade, access to a well-designed workspace heavily influences one's excitement in honing that trade. Before you begin cultivating, I strongly recommend getting each of the following workspaces properly set up and to acquire all the materials needed for your desired techniques.

The Transfer Space



For several cultivation protocols, mycelium must be moved from one container to another under aseptic conditions. Often this is done in a dedicated clean room and/or at a small station. Clean transfer spaces ensure the lowest rates of contamination as they minimize the movement of airborne competitors into the sterile interior of substrate containers. Several types of transfer spaces are listed below in order of lowest to highest cost and ease of use.

Convection Heat

When a Bunsen burner or propane torch is pointed upward, a convection current forms that pushes air-born competitors up and away from the area directly below a flame, creating a small sterile field. This makeshift sterile field works well for capturing cultures in a backcountry setting, but it is impractical for most other techniques.

Kitchen Oven

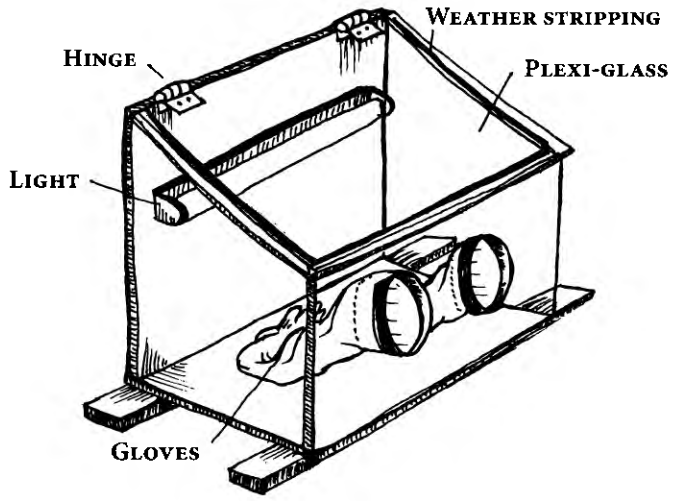
Setting an oven to high broil for 20–30 minutes will clean the air inside the oven. Once the oven has cooled to a point where it is comfortable to work within it, transfers can be performed inside of it as long as the air is noticeably warm.

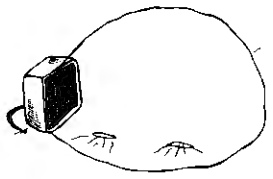
Clear Trash Bag

Here, materials are placed inside of a fresh, transparent trash bag that has been sprayed down internally with a disinfectant. Once loaded, the bag is tied off and the materials are manipulated from the outside. This technique prohibits the use of heat sources commonly used to sterilize tools.

Glove Box

A popular option, glove boxes are clean and (semi) sealed wooden, plastic, or cardboard containers that host a viewing window and (optionally) gloves. A variety of glove box designs exist but all should be big enough to allow mobility of the user's hands, be well sealed off from outside drafts, allow the user to clearly see inside, and be easy to clean with a disinfectant. Arms enter the box through holes cut in the front or sidewalls of the box. Permanent gloves can be installed in these holes to reduce air currents. A tall (ca. 3-foot [1 m]) box is recommended to accommodate for the height needed to easily inoculate tall containers, such as polypropylene filter patch bags. Prior to working in a glove box, wash all interior surfaces with soap and water and then with a disinfectant. Once the glove box is loaded with materials, close the lid and spray the interior with a disinfectant to "scrub" the air. Caution is advised when using alcohol to spray the glove box interior. If an open flame is present, a fireball can erupt inside the box. I know from personal experience!





Shmuv Box

This portable and discrete option uses a small High Efficiency Particulate Air (HEPA) filter to blow clean air into a large trash bag. Small holes cut in the bag for arms also allow for air to escape, creating a positive pressure environment inside. For all HEPA filters used in aseptic work, a 99.99% filtration efficiency is recommended. However, the 99.97% filters typically available for these small, personal-sized HEPA filters designed for home use also work well for many shmuv box users.

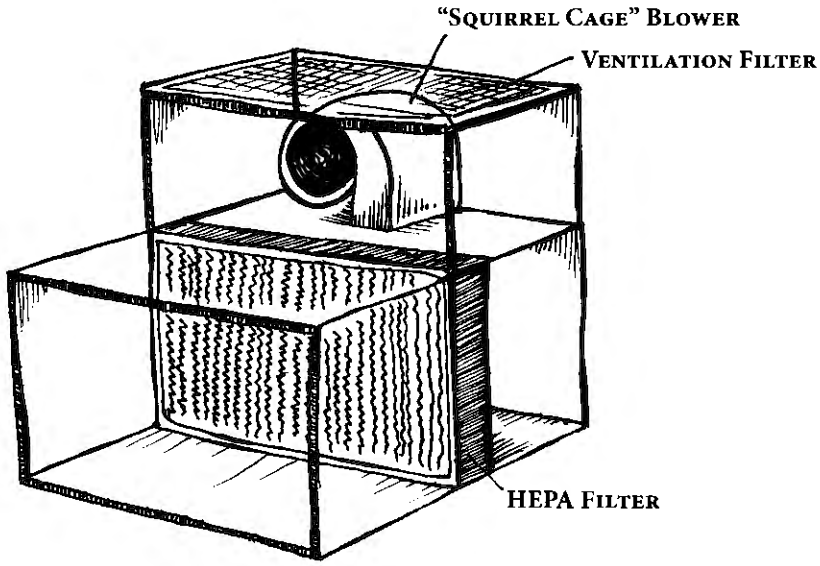
Laminar Flow Hood

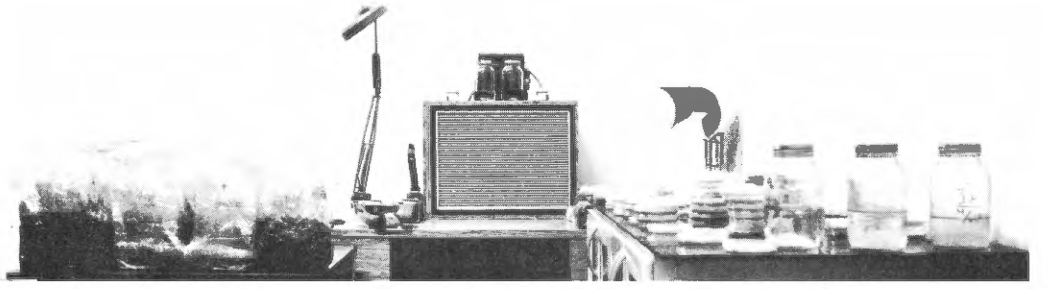
Here, a strong fan is used to blow air through a HEPA filter to create a sterile field in front of the filter. Flow hoods come in a variety of sizes and can be homemade or prefabricated. New HEPA filters can often be found online and should be able to obtain at least 99.99% filtration efficiency (this means it is filtering everything except viruses). High quality blowers can be bought online or found used from heating, ventilation, and air conditioning (HVAC) companies and indoor plant cultivation operations. Ask for "squirrel cage" blowers. The blower needs to be strong enough to push air through the filter and still produce a subtle wind in the transfer area. For a 12x24-inch (61x61 cm) filter, a blower able to generate around 500 cubic feet of air per minute (500 CFMs) is adequate. Universities and government surplus warehouses often auction off large flow hoods and other laboratory equipment at very low costs.

Air currents and eddies can develop at the edge of a flow hood and around objects, potentially sucking competitors into the workspace. Thus, building a wall around the work area is recommended. To ensure the airflow of a flow hood is consistent across its surface, move a burning incense stick in front of it while it is running, checking for any hot or dead spots.

It is recommended to run flow hoods for 15–45 minutes prior to working so as to blow away any microorganisms that may have settled into the filter since its prior use. Some cultivators will spray the surface of the flow hood for the same reason. Alternately, a cover can be placed over the filter between uses. HEPA filters should be tested every few months to determine their effectiveness. This is done by placing several freshly poured and opened agar plates in front of the flow hood for ten minutes. After ten minutes, cover and seal the plates and observe their rate of contamination over the following days.

Flow hoods are the most expensive option for a transfer space, but one that provides for the greatest ease in use. If one's work area is clean, a flow hood can have very low contamination rates. However, for workspaces that are not impeccable, glove boxes are ideal as all that one needs to be concerned about is the cleanliness of the interior of the box.





The Incubation / Spawn Run Space

Once inoculated, substrates are typically incubated in a warm space to encourage the mycelium to grow quickly. The mycelium does not need high levels of oxygen during incubation, but the air should be circulated on occasion to provide some fresh air and to discourage mold growth. Maintaining a clean incubation space is recommended. Incubation spaces should ideally be kept at around 70–72°F (21–22°C) to encourage rapid myceliation. Total darkness is not necessary for most species. Some species even benefit from periods of light during incubation.

Apart from dedicated incubation rooms, warm corners of a home can also house myceliating substrates. Space-saving strategies for spawn running include placing vessels above a refrigerator, on top of bookshelves, on the upper shelves of closets, or in a warm attic. Another accessible and often unused space in the home is the 1–2-foot (0.5 m) high area below the juncture of a wall and ceiling. Shelves placed here can discreetly house ample quantities of spawn to make efficient use of an unused vertical space that is located in a naturally warmer part of buildings. Decorative curtains can cover these shelves, or they can be left exposed to serve as a nice conversation piece. Jars and other vessels can also be suspended from high ceilings if wall space is not available.

Optional: The Incubator

The incubators discussed in Chapter 6 for growing fermenting fungi also have some applications for mushroom cultivation. Freshly poured agar plates can be placed in an incubator for 24–48 hours to test for the development of contaminants. The spawn of warm temperature tropical and sub-tropical species can be myceliated in an incubator to reduce the energy inputs required for heating a larger space. Likewise, if you are only growing a small amount of spawn, an incubator is a nice way to speed up mycelation rates while minimizing heating costs.

The Fruiting Space

In order for a mycelial network to produce an abundant yield of mushrooms, an area with a frequent supply of fresh, humid air and periodic lighting is typically required. Mushroom farms dedicate entire warehouses or large rooms to fruiting mushrooms, while the home cultivator can construct an array of small to medium sized areas to enable proper fruiting. The how-tos of designing fruiting spaces are discussed later.

Optional: The Bulk Substrate Prep Space

If you plan to cultivate with much regularity and at a moderate to larger scale, it is recommended to dedicate a space to substrate preparation. Depending on your needs, this might include an area for dry substrate storage; compost preparation; vermiculture; substrate shredding, chopping, mixing, and hydration; vessel storage, loading, cleaning, and drying; and bulk pasteurization and sterilization of substrates.

Optional: Cold Storage

Small closets or sheds can be insulated and equipped to serve as a walk-in cooler for spawn and mushroom storage, or to fruit cold temperature species during warmer months. Many farmers use a Cool Bot™[5] to trick an air conditioner to run at near-freezing temperatures. The ColdSnap Project has designed an open-source tool that accomplishes the same goal.[6]

Optional: The Bulk Dehydrator

If you are cultivating large quantities of mushrooms, having a place to dry them rapidly will ensure proper storage and help create value-added products. Designs for solar and homemade electric dehydrators can readily be found online.

Containers, Air Filtration, and Closure

The variety of tools and media used in the cultivation process are described throughout this chapter and summarized in Appendix F. For most practices, there are few options when choosing a tool for the job. However, one consideration that requires extra elaboration is the choice of container used for spawn production and fruiting, as well as its means for filtering air.

Jars

Glass jars are commonly used for growing spawn. While any pressure cooker-tolerant jar can be used, standard canning jars are preferred to avoid the game of match-the-lid-to-the-random-jar. Wide mouth jars are much easier to clean than narrow mouth jars. Cleaning jars is one of the most tedious aspects of cultivation—be prepared. All jar lids must allow for air exchange. Generally this is done by drilling a 3/16-inch hole in the jar lids and placing one of the following filtering materials over or through that hole:

- **Synthetic fiberfil:** Also known as quilt batting, this synthetic cotton substitute is a versatile filtration option as it does not absorb moisture and can be packed into any shape to filter the air passing through a small or large opening. For drilled lids, fiberfil is twisted, inserted through the 3/16-inch hole, and pulled until it will not move through the hole, even with some force applied. If the fiberfil is clean after spawn has been grown in the jar, it can be reused. However, if the mycelium encounters the fiberfil in a jar lid it will likely grow into and through the material, requiring the filter to be replaced.
- **Tyvek™:** This breathable, tear-resistant, non-absorptive, paper-like material can be found in office supply stores as shipping envelopes, in hardware stores as a

protective body suit, or as scrap vapor barrier from construction sites. For jar lids, high temperature (RTV) silicone is used to adhere a double layer of Tyvek over the 3/16-inch hole. If applied on both sides of the lid, a small air pocket forms which limits the spread of outside competitors in the event that the filter gets wet.

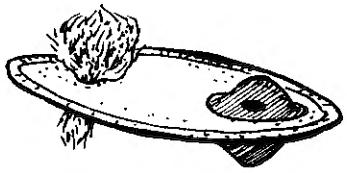
- **Micropore tape:** Commonly found in first aid kits, a double layer of this breathable material can be taped over the drilled hole to serve as a simple filter. This tape is typically not durable enough for repeated runs through the pressure cooker, requiring it to be replaced often. However, it's nice to have on hand for impromptu filter making.
- **Filter discs:** Employed by some mushroom farms, these relatively expensive filtration discs are not recommended for smaller scale cultivators. In my experience, they are prone to getting moist, which ultimately allows competitors to grow onto and through them, leading to contamination inside of the jar. Once these filters are myceliated with mold they should be discarded. Alternately, dirty discs can be soaked in a 10% bleach solution then rinsed and dried between uses, adding unnecessary labor. Filter discs are typically placed under a lid with a hole.
- **Medical air filters:** Low-profile, aesthetically pleasing, yet expensive Whatman™ air filters can be attached to a hole in a jar lid with high temperature silicone. These filters can contaminate in a manner similar to filter discs and are not commonly used by most small-scale cultivators.

Airport Lids

Regardless of the air filtration option you choose, I recommend modifying all of your lids to the "airport" style that is used for liquid culture work. Along with an air filter, airport lids have a second hole drilled in them that is plugged with RTV silicone. Once cured, this silicone serves as a self-healing injection site that allows for the passage of syringe needles into and out of a jar. This small modification is the central feature of the liquid-based cultivation practices discussed in *Radical Mycology*.

To make an airport, drill a 5/16-inch hole in your lid across from the air filter. Apply a pea-sized bead of RTV silicone to both sides of this hole, ensuring that a strong, tapering seal is made with the silicone to the lid. If there is not a good seal, the silicone might separate from the lid during use, leading to contamination of the jar's contents.

This basic design has been elaborated upon in a variety of ways. Some mycophiles prefer siliconing medical IV injection ports to a jar hole, adding an aesthetic value to the lid. However, these expensive ports can quickly wear out with repeated use. I like to keep things simple and use RTV blobs and fiberfil or micropore tape.



Making airport lids. Once cured and set up with a filter, these versatile lids can be used for most aseptic practices.

Polyethylene (PE) Bags

Cheap plastic bags made from polyethylene can tolerate pasteurization temperatures but not sterilization temperatures, making them a good option for pasteurizing sawdust or the substrates used for compost-loving species. Clean produce bags can be used but are prone to tearing. They are also often not transparent, disabling the cultivator from easily assessing the health and state of mycelial growth in the bag. Thick (3 mil) PE bags can be purchased in bulk from commercial packaging supply companies. PE bags do not have an air filter and thus need to be modified to allow for gas exchange.

Ceramic containers draw water away from substrates and are not suitable. Outdoor projects can make use of wooden and cardboard containers and are discussed in Chapter 9.

Polypropylene (PP) Filter Patch Bags *(a.k.a. Space Bags)*

These pre-modified, high temperature tolerant bags are the industry standard for cultivating and fruiting mushrooms. Unicorn Bags™ is the biggest producer in North America, selling a variety of bag and filter size options. Filters with a larger pore size provide a greater air exchange rate that encourages the initiation of fruiting in the bag. However, these larger holes also increase desiccation. The most common filter size is 0.5 μm. PP bags comprise the greatest pollution stream in the practice of mushroom cultivation. These bags can be cleaned and reused (with caution) two or three times, but this is not recommended due to the risk of contamination. Where possible, it is encouraged to use jars and other reusable containers for cultivating spawn and fruiting mushrooms.

PP5 Containers

Food storage and takeout containers made of polypropylene can withstand pressure cooking.

Plastic Containers

Any clean, moisture-retaining vessel can be used to grow mycelium and fruit mushrooms. Yogurt containers, plastic buckets, laundry baskets, storage containers, and garden pots are commonly used alternative containers for bulk pasteurized substrates. It really doesn't matter what kind of container you use as long as it accounts for the five fungal needs. Get creative!

Mushroom Nutrition

Understanding the nutritional requirements of macro fungi is central to understanding why some substrates are used over others and, by extension, how to create novel substrate recipes. Mushrooms, like all organisms, require a properly balanced diet to grow and function well. Without proper nutrition, a fungus will be unable to build cell walls, defend against competitors, produce medicinal compounds, digest toxic chemicals, or produce fully formed fruit bodies. Cultivators must feed their fungal allies well in order to support their growth and resilience, just as for any loved one. Commonly cultivated mushrooms require the following nutrients to thrive:

- **Carbon** (C): Carbon containing compounds are often the "energy source" for living organisms. C is required for cellular energy and to build cellular structures. Saprotrophic fungi naturally obtain much of their C from the sugars (e.g. glucose) and amino acids derived from the digestion of the cellulose, hemicellulose, and lignin in plant matter.
- **Nitrogen** (N): N forms the backbone of the numerous enzymes that fungi produce to defend, digest, and metabolize their substrates. Enzymes are a type of protein that accelerate and/or catalyze chemical reactions; they are responsible for facilitating the vast majority of the chemical-based functions of fungal growth and digestion. Without N, fungi cannot perform these functions or form chitin. The amount of available N in a substrate is thus a major limiting factor in the cultivation of mushrooms—when the substrate runs out of N, the fungus stops growing. To increase yields, cultivators intentionally add extra N to their substrates, often in the form of wheat bran or manure, depending on the species being worked with. Too much N can be counterproductive however as it can lead to abnormal growths, cause contaminants to proliferate, or enable the mycelium to grow so fast that it overheats in its container and kills itself. A concentration of 1–2% N is generally recommend for most substrate formulas. The fruiting stage requires more N than the vegetative stage. Organic forms of N, such as proteins and amino acids, are preferred. Some species can grow well with nitrates, though the growth of other species can be inhibited by this nitrogen source. Some species can utilize ammonium. A species that can utilize nitrate can utilize ammonium and organic N. Species that can utilize ammonium can utilize organic N. Urea should only be used to feed N to hot compost piles (don't pee on your mushrooms).

- **Oxygen** (O): Like animals, mushrooms use oxygen in numerous cellular processes, including the production of ergosterol. Oxygen is mainly supplied by carbohydrates, alcohols, amino acids, and other natural compounds.
- **Phosphorus** (K): K is used in the production of ATP, nucleic acids, and cell membranes. It is required at around 10^{-3} M.
- **Sulfur** (S): Fungi need trace amounts of S to make the amino acids cysteine and methionine. This can be provided in the form of biotin (vitamin B_7) and thiamine (B_1). Many fungi cannot synthesize these compounds; they need to be supplemented in some form. It is required at around 10^{-4} M.[7]
- **Potassium** (P): P is critical to certain enzymatic processes and fungal metabolism. It also influences the osmotic potential of hyphae. It is required at around 10^{-3} M.
- **Magnesium** (Mg): Mg is critical to certain enzymatic processes as well, including the energy storage of ATP. It is required at around 10^{-3} M.
- **Calcium** (Ca): Ca is important for cellular regulation and the transport of various ions, sugars, and amino acids across cell walls and throughout mycelium.
- **Vitamins:** Fungi cannot produce as many vitamins as plants and need some supplementation of these compounds, most notably the B vitamins. Thiamine is most commonly needed, generally at concentrations of 100 µg per liter. Higher concentrations do not seem to produce an effect.
- **Trace minerals:** Zinc (10^{-8} M), copper (involved in laccase production, 10^{-6} M), manganese (10^{-7} M), iron (10^{-6} M), and molybdenum are all needed in trace amounts for most species.

Substrate Formulation

Anywhere you go, there is likely to be at least one organic waste stream nearby that can be diverted for growing mushrooms. Some waste streams, such as hardwood sawdust and cereal straw, can be directly utilized for cultivating certain species with minimal additions. Other substrates may lack some of the required nutrients listed above. For these alternative substrates, the challenge is to determine their best combination, or *substrate formula*, that will both provide a well-rounded diet for a given species/strain and produce the highest yield.

The process of substrate formulation is governed by the nutritional requirements of mushrooms as well as by the nutrient profile of the available substrates. All substrates have their own average nutrient profile. Some plants form a relationship with nitrogen-fixing bacteria and have high levels of nitrogen, while other plants have deep roots that draw up trace minerals from the subsoil. Cardboard has been largely stripped of its original nitrogen and mineral content. The USDA offers average nutritional profiles for many plants, but these can vary significantly due to the following factors:

- **Soil quality:** Soil devoid of trace minerals will produce plants (and plant "wastes") that are devoid of these important elements.
- **How the plant was grown:** The quality of your substrates translates to the quality of your mushrooms. If possible, organic ingredients are encouraged to discourage the accumulation of heavy metals or chemical residues in or on the mushrooms.
- **Processing method:** Many food processing methods and substrate preparation methods leach sugars or other nutrients out of substrates, requiring the cultivator to later add these missing nutrients back in the form of a co-substrate.
- **The substrate:** Some plants, on average, produce and/or retain higher levels of certain compounds than others.

Substrate formulation is a bit of a guessing game, even for commercial farms and research institutes. In the last century, thousands of studies have been conducted around the world to compare the yields obtained by a given mushroom strain when it is grown on slightly different substrate formulas. For example, a given study might compare the yield difference between substrates that contained 1%, 5%, 10%, or 15% cottonseed husks as the only variable factor. Such a study might

Suggested Substrate Sources

Agricultural farms
Animal feed stores
Animal lots
Arborists
Coffee houses
Dumpsters
Furniture factories
Landscaping companies
Paper mills
Wood turners
Your kitchen or garden

According to a UN report, 1.5 billion tons of cereal straw, 952 million tons of bagasse, 6.48 thousand tons of coffee pulp, 6.15 thousand tons of coffee waste, 9.4 thousand tons of cotton seed hulls, 14 thousand tons of sunflower seed hulls, and 325 thousand tons of sisal were discarded as waste in 1999.[9] All are viable substrates that could have been used to grow fungal foods and medicines.

conclude that the substrate with 10% husks produced the highest yield. However, for the reader of this study, this conclusion should only be seen as a starting place to developing a substrate formula for that species. Even if that reader had the same strain as the study, it must be recognized that the cottonseed husks that were used in the study were grown under specific conditions in a specific part of the world. Cottonseed husks obtained from another source may produce a different effect on the substrate formula. Do not assume that the substrate formula preferred by one cultivator will be the best for your different substrate source and/or different species/strain.

If you are considering starting a mushroom farm of any scale, it is recommended to take the research and development time up front to determine the best substrate formula for the species and strains you are working with. To begin, use the substrate formulas offered in this chapter and in Appendix H and adjust the ratio and presence of the base ingredients in various proportions to create 5–10 slightly different formulas. Inoculate, incubate, and fruit these formula iterations under the same conditions and compare the ultimate weight and quality of their respective yields. Also do some research online to compare various substrate formulas that have been used to fruit the species you are working with.[8] Lastly, consider acquiring or developing several strains and comparing their growth qualities.

What About C:N?

One measure of a substrate is its balance of carbon to nitrogen, known as the C:N ratio. This measurement is most commonly considered during the production of hot compost for compost-loving mushrooms. For wood-loving species, C:N ratio requirements vary widely by species, strain, and stage of growth. Substrates around 40:1–60:1 seem to be preferred by most wood-loving fungi. Fungal hyphae typically have a C:N of 10:1. One-third of the C in a substrate is used for growth, while the other two-thirds are expired as CO_2.

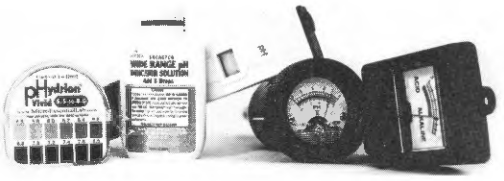
Acidity vs. Alkalinity

Chemical reactions are influenced by the relative amount of positively-charged hydrogen ions (H^+) and negatively-charged hydroxide ions (OH^-) that are "floating" in the environment. When there is a relatively high amount of hydrogen ions, the environment is said to be acidic. When hydrogen ions are low in centration and hydroxide ions predominate, the environment is said to be alkaline. The degree of a material's acidity or alkalinity is measured with the pH scale, which ranges from 0 (acidic) to 7 (neutral) to 14 (alkaline/basic). Pure water has a pH of 7.

The pH of a substance directly influences the number, type, and speed of the chemical reactions that occur within that material. As the processes of mushroom digestion and metabolism are largely driven by the chemical reactions of enzymes, the pH of a substrate will directly influence the rate at which a fungus will be able to grow and digest its food. Many species can only function within a specific range on the pH scale. Generally, this tolerance is in the acidic end of the scale, reflective of the slight acidity of most forest soils and wood. Most species/strains tend to grow in the 4–8 range, with 5.5–6 being the average. Some are tolerant of a wide pH range. Others only function within a few points on the scale.

Because the pH scale is logarithmic, slight pH adjustments are easy to make but larger movements of, say, two points on the scale require much more of an acidifying or alkalinizing agent.

While the tried-and-true substrate recipes presented in this chapter do not generally require pH measurement, the pH of novel substrate formulas should be tested using test papers or meters and adjusted as needed. Generally a substrate is too acidic and needs to have its pH raised with the addition of an alkalinizing supplement, such as hydrated lime. The digestive products of fungal digestion tend to acidify substrates. If the fungus makes their substrate too acidic, it will be no longer be able to grow. For this reason, cultivators may add a pH "buffer" that helps stabilize a substrate's pH regardless of the acidifying effects of the fungus. A variety of alkalinizing additives and pH buffers are discussed in Appendix H.



A variety of tools and reagents can be used to test the pH of a substrate.

Measuring a Formula's Success With Biological Efficiency

The success of a given substrate formulation is measured by the quality and weight of the mushrooms it produces, relative to the weight of dry materials used to make up the substrate. This comparison of fresh mushroom to dry material weight is known as measuring the "biological efficiency" (BE) of the substrate. For example, if 5 pounds of dry materials produce 4 pounds of fresh mushrooms, the substrate/strain combination is said to have an 80% BE rate. Six pounds of mushrooms produced from 5 pounds of dry substrate reflects a 120% BE. Some substrates and strains may produce a 200% BE, though 100% BE is the minimum hoped for from most species/strains.

Putting it All Together

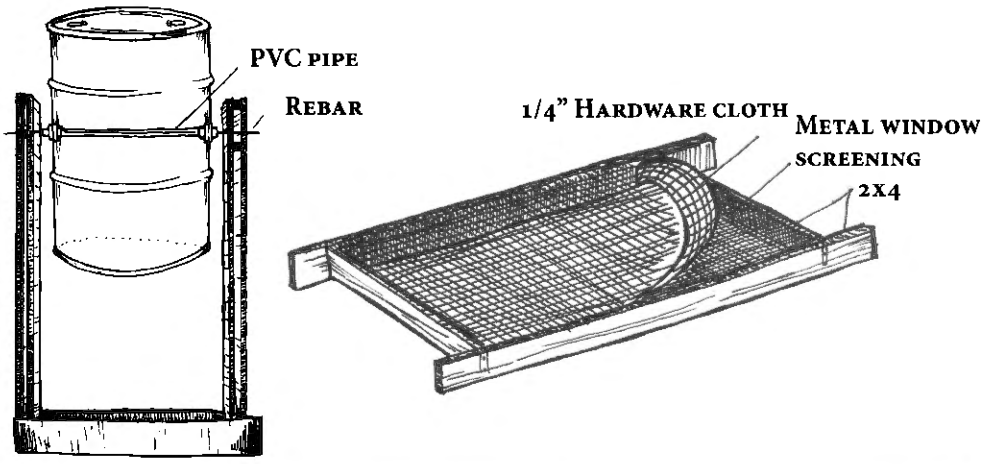
Many of the species we grow prefer a hardwood-based substrate. If you have an abundance of hardwood species in your area and can get access to their limbs, logs, and chips, consider yourself very lucky and start growing some wood-loving species. If you are using tree species that are not commonly used in cultivation, experiment with mixing wood types and adding varying amounts of nitrogen and mineral supplementation to determine the best substrate formula. Check the pH of any novel formula and adjust accordingly to meet the needs of the mushroom species you are working with.

Most people have a hard time sourcing hardwood. If this is your situation, an alternative is to grow a species that can fruit on straw, coniferous wood, compost, or manure-based substrates. In this scenario, the first step is to determine all the available organic waste streams in your area and determine which species you can grow on these sources. Straw or similar low-nitrogen agricultural wastes can work well on their own for most species that grow on straw. A nitrogen and/or mineral supplement may be helpful, but do not add too much nitrogen as over-supplementation can lead to a contaminant bloom. If cow or horse manure is abundant, supplement the manure to increase its aeration and nutrient profile, as discussed later in this chapter. Check the pH of novel formulas. Other manure types are not generally preferred due to their physical quality, state of decomposition, and nutrient profile. But feel free to experiment.

A short online search for your species of mushroom and terms like "substrate formula" will pull up multiple studies comparing different formulations.

If other agricultural waste streams are abundant, the best options would be to compost them for compost-loving species, or to try growing Oysters or King Stropharia on them. Depending on the substrates used and the soil they were grown on, your formula may be lacking in one or more nutrients that the mushrooms require to grow. Again, play with various substrate combinations to formulate an ideal recipe and compare their effectiveness with BE.

Mixing up iterations of a soft wood sawdust substrate formula.



TWO CENTRAL PIECES OF EQUIPMENT

(Left) A substrate tumbler made from a plastic 55-gallon drum that pivots on a rod of rebar helps to easily mix substrates.

(Right) A heavy duty mixing screen used for hydrating substrates or draining grains. These can be built to any size. Mine is 3 feet (1 m) wide and 4 feet (1.3 m) long.

SELENIUM-RICH MUSHROOMS

As fungi digest their substrates, they tend to concentrate trace elements into their fruit bodies. Cultivators can intentionally take advantage of this phenomenon by introducing essential micronutrients into their substrate formula. In several studies, researchers have intentionally added the element selenium into sulfur-poor substrate formulas to achieve this effect. As selenium is located below sulfur on the periodic table of elements, fungi can uptake the selenium (generally applied as sodium selenite [a common food supplement] or selenate salts) in place of sulfur to create various organic selenium compounds in their tissue.[10] The result is a mushroom filled with this element in a bioavailable form. This is beneficial as selenium binds with mercury in the human body, making it non-toxic, and also seems to reduce cancer rates. Further, selenium is a necessary cofactor in the glutathione peroxidase enzyme system that helps remove free radicals from the body. Sodium selenite can be added to fruiting substrate formulas, grain spawn, or liquid media. In one study, a concentration of 20 µg per milliliter of sodium selenite was found to be an optimal concentration for the cultivation of Shiitake mycelium in liquid media.[11]

Cleaning Substrates

Depending on the cultivation process being undertaken, cultivators "clean" their substrates by either sterilizing the material with heat or by pasteurizing it with heat or other means. Sterilization and pasteurization are not the same process; each are used for different reasons and with different tools and procedures.

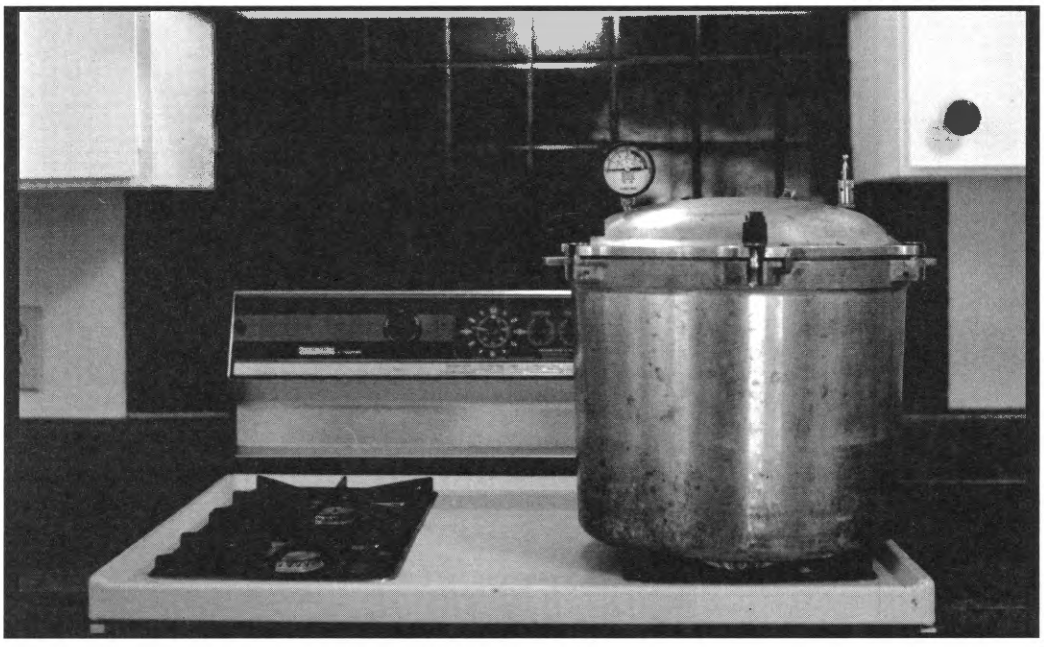
STERILIZING SUBSTRATES

Sterilization is intended to kill all living organisms by maintaining above-boiling temperatures (approximately 250°F [121°C]) for a sustained period of time. Theoretically, all organisms can be killed at this temperature in 15 minutes. However, longer time periods are called for in many practices to ensure that the heat thoroughly penetrates the dense materials used in cultivation. After sterilization, substrates are a "blank slate" on which many microorganisms can easily grow. As such, sterile substrates need to be inoculated under aseptic conditions to avoid contamination from competing organisms. Agar and liquid media, grains, and nutrified sawdust are the most frequently sterilized substrates.

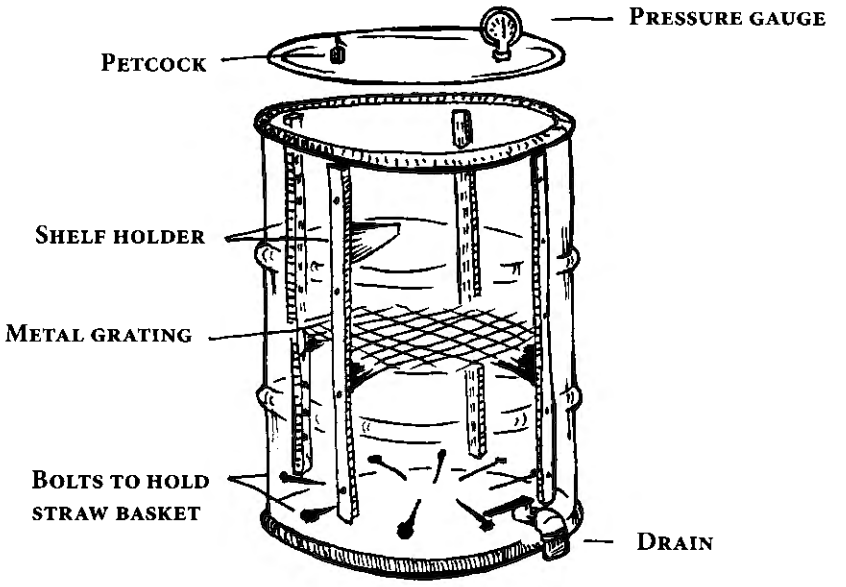
Pressure Cookers and Autoclaves

Most home cultivators and small farms use a pressure cooker (PC) to sterilize substrates and tools. PCs come in a wide variety of shapes, sizes, and price points. Investing in a high quality PC, such as those by the brand All American™, is recommended. If you are able to find a high quality used PC, ensure that it is not cracked. A cracked PC can blow up! Smaller PCs can be heated on a stovetop while larger models may require a propane burner. Proper PC usage is essential for safe and effective cultivation. Always read the instruction manual for your PC for specific details.

1. Put enough water in the bottom of the PC so that by the end of the pressure cooking there is still some water left at the bottom of the PC. For most runs, 0.5 inches (1.25 cm) of water is sufficient. Never run the pressure cooker dry!
2. Place your materials in the PC and securely close the lid. If using a "rocker top" pressure release system, leave the weight off the vent port. If using a "petcock" pressure release, open the petcock. Turn the heat source to a level that requires 15 minutes to pass before steam begins to flow from the petcock or vent port. Heating the PC too rapidly can cause jars to break.
3. Allow a steady jet of steam to escape from the pressure release vent for 1–5 minutes and then place the weight on the vent port or close the petcock. This ensures that everything heats evenly. The PC will quickly come up to pressure in 5–15 minutes. Once the desired pressure is reached (typically 15 psi), reduce the heat level on the burner until the pressure stabilizes. It may take a few minutes of adjusting the heat to get it just right. If using a "rocker top," adjust the heat source so that the rocker maintains a slow, steady rocking motion and/or jiggles once a minute or so.
4. Once the pressure is stabilized, start your timer. You will need to sit with the pressure cooker during the entire run to make sure the pressure remains constant and to adjust the heat accordingly. Cook your materials for the specified run time. If you are above 2000 feet (6000 m) in elevation you will need to add 5% to the cooking time for every 1,000 feet (300 m) (i.e. at 3,000 feet [900 m] add 5%, 4,000 feet [1,200 m] at 10%, etc.).
5. When the run time is over, turn off the heat source and walk away to let the PC cool and de-pressurize on its own. I do much of my PC work at night so that everything is cooled by the following morning.

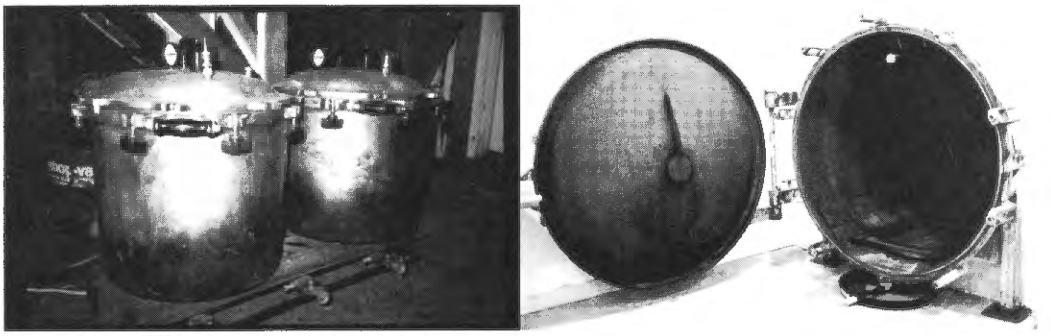


A familiar sight.



A converted 55-gallon, food grade steel drum can be converted to serve multiple functions. Bolts in the bottom of the drum hold up baskets/bags filled with substrates to drain after pasteurization. Adjustable shelves and thick metal racks hold jars or bags of substrates for steam sterilization.

If scaling up, investing in an electric, automated pressure cooker or pressure sterilizer such as those made by All American™ and Yamato Scientific™ will help avoid the hassle of monitoring pressure levels and constantly adjusting a heat source. Autoclaves are laboratory devices that perform essentially the same function as a pressure cooker; they may be small or enormous. Larger mushroom farms use walk-in autoclaves that are able to sterilize hundreds of pounds of substrate in one run. Kegs can be retrofitted into large sized pressure cookers and 55-gallon steel drums or 60 gallon steel wine barrels can be modified to serve as low pressure (3–4 psi) autoclaves.[12] In these two DIY approaches caution is highly advised; a metal vessel that is cracked and/or under improperly controlled pressure can blow up!



(Left) Oversized pressure cookers must be heated on a propane burner.

(Right) A 20-foot long autoclave at Smugtown Mushrooms in Rochester, NY.

Fractional Sterilization / Tyndallization

The pressure gauges on PCs can go bad over time and should occasionally be tested for accuracy. In the US, most universities have county extension offices that do this testing for free. Inaccurate gauges cannot be fixed and should be replaced.

If you do not own a pressure cooker, the process of *fractional sterilization* or *tyndallization* is a slow, old school means of sterilizing substrates. Here, sealed vessels are heated in a steam bath for 30 minutes, 3 days in a row. Between steam treatments, the jars are kept warm (85–98°F [30–37°C] is ideal, but room temperature will work). This heating and incubating process germinates heat-resistant endospore bacterium, making them vulnerable to latter heating stages.

1. Place vessels in a cold, shallow (2–4 inches [5–12 cm]) water bath inside of a pot with a heavy lid. Glass jars should be resting on a small towel or on canning jar lid rings to keep them off the bottom of the pot.
2. Bring the water to a boil to heat and steam the vessels at 212°F (100°C) for 30

minutes. Living bacteria and fungal spores are destroyed in this treatment but endospores survive.
3. Incubate the vessels overnight to germinate dormant endospores.
4. The next day, heat and steam at 100°C for 30 minutes to kill the germinated endospores.
5. Incubate the vessels for a second night to germinate the remaining endospores.
6. The next day, heat and steam at 100°C for 60 minutes to kill the remaining endospores.

Discovered by J. Tyndall in the mid 1800's, tyndallization predates pressure cooker use by over 100 years.

Dozens of bags or jars of substrate can be tyndallized together in a large vessel such as a 55-gallon drum retrofitted with racks. These bags should be steamed for two or more hours on each of the three days to ensure adequate heating and endospore germination throughout the substrate. Insulated metal dumpsters could also be used, however the increased heating times required to adequately warm the large mass of substrates and achieve endospore germination may prove less efficient than heating the same number of bags in a series of 55-gallon drums.

Pressure cookers are able to reach above-boiling temperatures due to a physical relationship between the boiling point and pressure of a gas: as one increases, so does the other. This is known as Boyle's law.

A Note on Safety

Mushroom cultivation is a rather simple, repetitive, and low-risk process. The greatest threats to the cultivator come from the improper use of a pressure cooker or autoclave, or getting cut with glassware. Jars can crack in the sterilization process and break during handling. Chipped jars can cut one's hands while being washed. Otherwise, general caution with lifting heavy objects, working around open flames, and using hypodermic needles and scalpel blades should be heeded when appropriate. Safety first!

Pasteurizing Non-Hydrated Substrates

With pasteurization, substrates are heated to 140–170°F (60–77°C) for 1 hour to kill the *mesophilic* organisms that die above 113°F (45°C). *Thermophilic* microorganisms that thrive in higher temperatures can survive this heat treatment and thereafter stay alive on the substrate to "protect" it from other microbes. These substrates and protective microbes are later consumed by the mushroom mycelium. Pasteurization allows for substrates to be inoculated in open air and relatively dirty environments. Substrates that are commonly pasteurized include agricultural waste materials, manure, composts, casing materials, and plain (non-nutrified) sawdust.

Hot Water Soak

Agricultural waste based substrates (e.g. straw) are traditionally pasteurized by immersion in a hot water bath. On a smaller scale, these substrates are placed in a pillowcase or burlap sack and submerged into a large pot of 170°F (77°C) water. When the material is inserted, the water temperature will drop to around 160°F (71°C), which is ideal. The substrate temperature is monitored with a thermometer set in the center of the substrate and the heat source adjusted as needed to maintain an internal substrate temperature of 140–170°F (60–77°C) for one hour. After an hour has passed, the substrate container is lifted and set to drip and cool above the pot for a few hours or overnight.

If scaling up, a large wire basket or multiple burlap sacks of substrate can be submerged in a 55-gallon drum filled with 180°F (82°C) water and covered with a lid. The water temperature will drop to 160°F (71°C) with such a large influx of material. The substrate temperature is then be monitored and the heat source adjusted to maintain a temperature of 140–170°F (60–77°C) for one hour. Typically the water stays at the proper temperature and does not require additional heating. After an hour, the basket is lifted and set to drain above the drum. A pulley system or electrical wench can assist in lifting the heavy basket. Alternately, a drain can be installed in the bottom of the tank, allowing the substrates to drip-dry under the lid of the tank, staying clean. Once the material has stopped dripping, it can be spread out to cool on a clean surface such as a tarp or large metal table

Electric water heater coils can be retrofitted into 55-gallon drums to heat water to pasteurization temperatures. Some farms also modify on-demand water heaters to produce pasteurization-temperature water, which is then fed into the pasteurization tank(s) with a hose. Both approaches consume a large amount of electricity and are not as energy efficient as other alternatives.

that has been cleaned with soap and water and then wiped with a disinfectant. Hot water produced by thermal vents or hot springs offers a zero-input approach to pasteurizing substrates.

Biochar Stoves and Rocket Mass Heaters

These fuel-efficient stove designs both produce an ample amount of heat that can be utilized to heat water to pasteurizing temperatures. Biochar stoves are discussed in Chapter 9. Designs for rocket mass heaters can be found online.

Solar Water Heater

Water can easily be heated to pasteurization temperatures using low impact solar water heaters made from recyclable materials. A wide variety of solar water heater designs exist. Well-insulated solar heaters are surprisingly effective on cold days, as long as the sun is shining. If placed on a roof or at a slightly higher elevation than the pasteurizing vessel, the water can easily flow with gravity, minimizing the labor and energy required to treat the substrate.

Hot Compost Water Heater

The practice for making hot compost-based substrates is described later in this chapter. These compost piles produce a significant amount of heat that can be utilized in a variety of ways. Hoses can be coiled in the center of these piles to rapidly heat water to near or above pasteurization temperatures. As the hose may interfere with the constant turning these piles require, a dedicated large hot compost pile may be desired to provide a constant hot water source for pasteurization and outdoor showers. Four hundred feet (122 m) of 1-inch (2.5 cm) hose coiled inside of a large compost pile can produce around 40 gallons (150 L) of hot water and recharge in about ten minutes.

Cold Water Fermentation

Fermentation is a low-input means for "pasteurizing" substrates. Here, the substrate is submerged in standing water to create an oxygen-free (anaerobic) environment. In this state, the dormant anaerobic bacteria that are present on the substrate will soon awaken and multiply, eating aerobic (oxygen-dependent) bacteria and mold spores on the substrate. Depending on ambient temperatures and the nutrient profile of the substrate, in 7–14 days the substrate will smell somewhat foul and the water surface will be covered in a thin layer of slime. This is good; it means that the fermentation was successful. The substrate is then removed and suspended above the fermentation tank to drain until water stops dripping from the substrate. Alternately, the entire soak tank can be turned upside down to allow the substrate to drain. During this draining period the anaerobic bacteria die, leaving the straw "clean" and ready to use for inoculation or installation. Trashcans and other vertical containers are commonly used for fermentation, though 5-gallon buckets work well for smaller operations. Adding several gallons of water from one fermentation batch can serve as a "starter culture" for a subsequent batch, speeding up the rate of fermentation.

It Depends

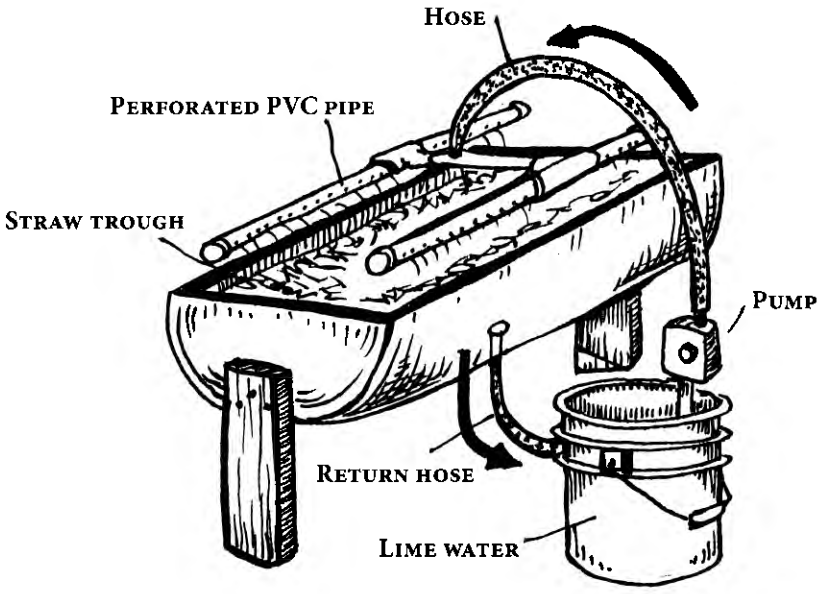
When I teach cultivation, I am frequently asked whether certain hypothetical cultivation scenarios will work. Often, these project ideas sound feasible but, having not done them myself, I cannot give a definitive answer to their questions. So, instead of discouraging curious investigation, I give the most honest answer that I can: "It depends." This It Depends Clause (IDC) is due to the fact that the success of any cultivation practice or experiment is dependent upon numerous factors that make it difficult to assume exact expectations on yields and time frames. Species and strain; substrate source, age, and preparation; inoculation timing and rate; incubation and fruiting parameters; and luck all contribute to the speed and success of any project. Following the principles and protocols outlined in this chapter should get you on your way toward innovation and elaboration (experimentation is encouraged!). But, for all uncommon cultivation scenarios, results will vary.

Chemical "Pasteurization"

Several chemical-based methods have been devised to "pasteurize" substrates:

- **Hydrogen Peroxide:** Caustic 27% hydrogen peroxide can be used to treat some substrates, such as straw. This method was developed by Rush Wayne and his booklets are available online for those interested in this method.[13]
- **Lime / Wood Ash:** When straw is soaked in highly alkaline water, the rapid shift in pH effectively kills most microorganisms. An easy way to raise the pH of water is to add hydrated lime ($Ca[OH]_2$) at a rate of around 0.5 cups per 14–16 gallons (53–60 L) of water until a pH of 12–13 is reached. The straw is then submerged in this water for 4–12 hours. After soaking, the straw is drained well and then inoculated as normal. The resulting straw will be quite alkaline, limiting the species that can be grown on it mainly to Oysters, which are tolerant of a higher pH range.

  To minimize wastewater, lime water can be circulated through a trough holding dry substrates by using a water pump that sprays that water until hydration is achieved. Excess lime water can be used for subsequent treatment batches, just be sure to add more lime as needed to maintain the proper pH. After the water is used, add an acid such as HCl (sold as muriatic acid) to the water to bring the pH as close to neutral as possible before disposing of it. An alternate alkalinizing agent is wood ash, which can be used in a similar manner as lime.



Pasteurizing Pre-Hydrated Substrates

Plain sawdust and (faux) compost-based substrates are carefully mixed and hydrated prior to pasteurization. Placing these substrates directly in a hot water bath will offset their moisture content, an undesirable act. These pre-hydrated substrates should instead be pasteurized by any of the following methods that utilize conductive heating.

Hot Water Bath

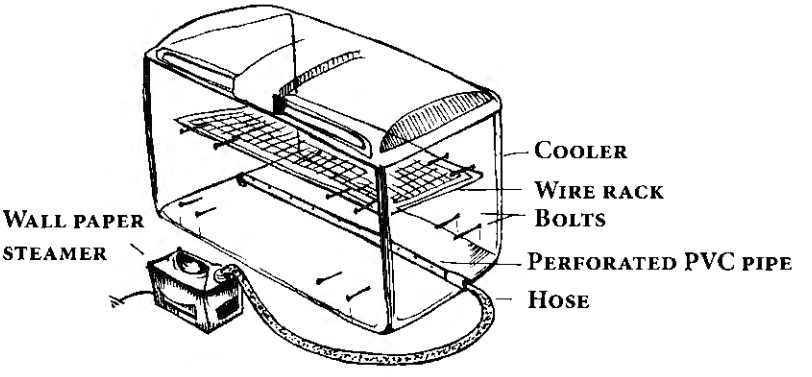
Here, glass jars or polyethylene bags filled with substrates are placed in a bath of *cold* water and, if needed, held down with a weight. Jars should be placed on a small towel or a layer of canning jar rings to prevent cracking. A thermometer is placed in the center of one of the vessels and the pot's water is brought up to a boil. The temperature on the thermometer will start to climb once the

water's heat has reached the jar's core, generally after an hour or so. When the thermometer reads 120–130°F (49–54°C), the heat can be turned off. The substrate's temperature should continue to rise. Sitting in the hot water bath, the substrate will generally plateau around 150°F (66°C) for the hour needed to complete pasteurization. After the hour, the containers are removed from the water and left to cool overnight.

An electric wall paper steamer can be connected to a cooler, or chest freezer to steam treat large amounts of substrates. I also use my cooler as an incubator and solar cooker, thereby increasing space and functional efficiency.

Steam Bath

Channeling steam into a large insulated box is an ideal way to quickly pasteurize large quantities of substrates while avoiding the hot mess of the water bath method. This steam can be produced by an electric wallpaper steamer, a retrofitted pressure cooker, or a home built steamer unit made with a water heater element. The temperature of the substrate should be measured by occasionally checking a thermometer set into one of the center containers of substrate or, better yet, externally with a remote (barbecue) thermometer.



Passive Solar

Solar heat can be collected and held in a well-insulated, reflective box that contains multiple vessels filled with pre-mixed substrates. Coolers, deep freezers, and old refrigerators are good options for a pre-built container. Other recycled boxes and containers can be insulated with straw, balls of newspaper, or plastic bottles filled with sand to create low-cost containers for solar heat collection. Temperatures are monitored in the same ways as with the steam bath method. Similarly, substrate containers can be placed in a sealed car on a hot day as long as they stay at 140–170°F (60–77°C).

Compost Heat

The thermophilic compost piles used for making compost-based substrates (discussed later) are designed to maintain pasteurization temperatures for days. If you are making hot compost, a great way to take maximum advantage of this heat source is to place containers full of substrates into the interior of these piles to passively heat the materials over the course of a few hours. To keep your vessels clean, bury them inside of plastic bags. Temperatures are best checked with a remote thermometer.

CAN I REUSE THE WATER?

A second round of straw can be soaked in hot water treatments. After this second round, this hot water will be too nitrogen-rich for further straw treatments. However, it can be used to soak grains, hydrate sawdust, supplement agar or liquid culture recipes, or diluted and poured onto an outdoor mushroom bed or a sluggish hot compost pile. This nitrogen-rich water should not be used on plants without dilution with water (1:4). The water from fermentation processes, if poured directly on the ground, could upset microbial communities in the soil. A better use for this water is to pour it onto a slow compost pile that is already rich in anaerobic microbes.

Notes on Substrate Treatment

If you can spare the materials, leave one plate, jar, or bag of substrate uninoculated after sterilization treatments. If these "blanks" are sealed and stored in the same manner as the rest of the inoculated containers, they can help determine if a sterilization method was adequate. If the container becomes contaminated, then the time frame, temperature, or tools of the sterilizing process should be assessed for improvement.

Convention dictates that once a substrate is sterilized or pasteurized it should be inoculated as soon as possible to avoid contamination. However, I have had low contamination rates using heat-treated substrates that I left uninoculated for days or even months. If the container is well-sealed and the heat treatment was done properly, contaminants should theoretically not be able to enter. If air filters are covered, drying of the substrates can be minimized. Thus, instead of feeling rushed to make spawn within a specific time frame, consider having substrates cooked and on hand in the event of needing to perform a last minute transfer.

For large-scale operations it is recommended to track the rates of contamination that occur at each stage of the operation. An average contamination rate of 1–2% is good. Less than that is exceptional.

Questions to Consider

Before beginning any new cultivation project, account for all of the hurdles that you may confront down the road. The following questions are some of the more commonly encountered choices that determine the course of a given project, some of which will make more sense after you have thoroughly integrated the information in this chapter. This is not an exhaustive list.

- **Substrates:** What substrates are locally available? Is there an abundant and suitable wood source nearby? Or should I focus on developing a nutrient-balanced compost for compost–loving species? Is my best substrate option coffee and cardboard? Questions like these will help narrow down which species you can easily grow.
- **Species/Strain:** Which species do I want to grow? Some species are easier to grow than others due to their inherently aggressive, defensive, and fast growth habits. Some species are better suited to temperate weather, others to tropical climates. Many exotic mushrooms taste great and are highly medicinal but have a very small market in Western cities.
- **Scale:** Personal use, community lab, or farm scale? How much storage space do you currently have for incubating spawn? If you scale up in the future, will you have adequate space to expand? How much substrate can you prep at one time? How many containers can you fill and inoculate in an hour? How many containers fit in your fruiting space? Do you or your community members have adequate time to maintain and manage spawn production? This last question is especially important as cultivation projects that start with great enthusiasm can quickly turn into an overwhelming endeavor to keep up with. Splitting up the cultivation and maintenance workload amongst several people is encouraged.
- **Tools and Teks:** Of the variety of approaches and tools used to grow mycelium, which route is best suited to your needs, budget, and time/energy capacity? The monetary cost of investing in high quality equipment will be returned in the form of significant time and energy saved on labor. The success, ease, and longevity of a cultivation project is directly based on the functionality and flow of the tools and methods used. Ensuring that your operation is as enjoyable, smoothly running, and stress-free as possible will help mitigate burnout and one's loss of interest in the art of cultivation. This last point cannot be overemphasized.

Mistakes are great, the more I make the smarter I get.
—Richard Buckminster Fuller

Mental Preparation and Self Care

As with learning any new skill set, gaining a solid familiarity with the practices in this chapter takes dedication and time. To pave a gentle path into the world of cultivation, I recommend starting slowly with some of the projects listed in Appendix J. Developing a zen-like sense of patience and humility is also helpful if you are just beginning. Try to accept up front that some projects will never grow or fruit, while many others will inevitably get contaminated. See all of your projects—the successes and failures—as steps up the ladder of mycognosis. This does not imply that you need to be discouraged before you even begin. Rather, I consider mushroom growing to be its most engaging when it is coupled with a feeling of adventure and an embracing of the unknown.

Be sure to pay close attention to your work habits. Often, cultivators develop such a codependent relationship with the mushrooms they grow that they become tied to their projects—the most devout staying up late to culture far beyond the witching hour. If you notice any semi-obsessive habits developing in yourself, take a moment to pause, assess your needs and capacities, and perhaps scale back your list of myco-to-dos to a manageable number. There is always more to learn in this field, so save something for tomorrow, or next month, if you start to feel overwhelmed. Working with a mentor or group of friends significantly helps remove many stressors associated with learning to cultivate. Plus, it's a lot more fun to nerd out on mushrooms with other people. Don't be afraid to ask for help and build connections amongst other Radical Mycologists.

Stage 1: Agar and Liquid Inoculum

This section begins the in-depth exploration of the protocols of indoor cultivation. At nearly every step in the four stages of growing mushrooms, several options are presented for how one can proceed. While some techniques are quicker and more appealing than others, all serve to reach the same end result. Once the preceeding principles and techniques are thoroughly understood, most cultivators come to develop their own nuanced approach to cultivating—the choose-your-own-adventure of myceliation.

The first step toward growing fruit bodies is to obtain a healthy and competitor-free culture of mycelium. Traditionally, pure mycelial cultures have been isolated through the manipulation of spores or fungal tissue in a petri dish filled with nutrified agar. However, the refinements in home-scale liquid-based inoculum cultivation that have been developed in the last decade provide many benefits over agar work. But, as both techniques have their own disadvantages, it is recommended to master agar and liquid inoculum production to help refine and hone your cultivation skillset, thereby enabling greater flexibility during experimentation.

About Agar

Gelatin was used for many years as the firming agent in petri dishes. However, the fungi cultivated on these plates would quickly digest this protein, creating a wet mess. Agar was later standardized, as fungi do not liquefy it. Agar (a.k.a. agar-agar) can be bought online or in bulk at health food stores. It is vegan and rather expensive. Powdered and granular agar work equally well as they both melt sufficiently during pressure cooking.

Agar can be extracted from seaweed with a little effort. First, thoroughly wash and sun dry the seaweed then mix it with 15 times its volume in water and soak for 24 hours. Process this mixture in a blender and pressure cook the resulting pulp at 20 psi for 3 hours. Filter the cooked pulp through cheesecloth and pour the liquid portion into a baking tray to cool and solidify. Place this tray in a freezer for 24 hours. The next day, remove the frozen material and place it on a screen to allow the water to melt away, leaving the agar behind. Ideal seaweed species include those in the genus *Pterocladia*. Be sure to check and balance the pH of media recipes using homemade agar. If you want to save money on agar, other alternatives are mashed bananas and brown rice paste.

Agar

Agar is a seaweed-derived, gelatin-like substance. For cultivation work it is mixed with water and other nutrients, cooked, sterilized, and then cooled inside of small containers to form a semi-solid horizontal platform on which a mycelial network will grow two-dimensionally. Commonly referred to as *plates*, petri dishes filled with nutrified agar are inoculated with spores or a piece of mushroom tissue. Once a contaminant-free mycelial network is established (usually after a week or two), pieces of the myceliated agar are moved from the plate to another plate or to a different substrate.

Working with agar is one of the most cumbersome and contaminant-prone stages of the cultivation process and, personally, my least favorite. However, it does have several distinct applications that make learning the skill of working with agar indispensible to the experimental cultivator. These include the ability to:

- Remove competitor microorganisms from cloned mushroom tissue.
- Begin multi-spore inoculations to isolate and develop individual strains for experimental purposes.
- View, compare, and facilitate the various responses of mycelium to chemicals and other organisms.

Agar Media Formulation

Agar is nutrient-poor and must be supplemented with carbohydrates, proteins, vitamins, and minerals to ensure healthy mycelial growth. Common sources of these additives include:

- **Carbon:** Provided by dextrose (corn sugar), light malt extract (from beer-brewing supply companies), cereal flours, oatmeal water, or the broth made from boiling potatoes. Some cultivators prefer to mix carbon sources for more robust recipes.
- **Proteins:** Cereal flour, soy peptone, and potato water provide different proteins and amino acids.
- **B Vitamins:** Supplied by baker's yeast or nutritional yeast.
- **Minerals:** I typically add a pinch of gypsum to each liter of agar to provide additional calcium and sulfur to the recipe. A few drops of a liquid trace mineral concentrate is an optional, experimental additive. Just be sure the concentrate does not include silver, which is antifungal.

For most agar formulas, it is recommended to add 3–5 grams of the grain and/or fruiting substrate that will later be used to grow the fungus. Introducing these substrates early on stimulates the mycelium into producing the digestive enzymes it will later need to effectively break down the substrates, leading to quicker myceliation and fruiting times.

When cloning wild harvested mushroom tissue, an optional additive is an antibiotic. Gentamycin (at 20 milligrams per liter) and streptomycin are two commonly used antibiotics that can withstand autoclaving and thus can be added to the agar at mixing. Food grade 3% hydrogen peroxide is a cheaper antibiotic option, but it does not withstand the high temperature of the pressure cooker. Hydrogen peroxide (H_2O_2) must be added to the agar once it has cooled to below 140°F (60°C) at a rate of 6–10 milliliters per liter of agar. This temperature can be measured with a clean thermometer or an infrared thermometer. Some cultivators add activated charcoal to their agar at a rate of 10 grams per liter as a bacterial suppressant and spore germination promoter.

It is recommended to change agar formulas at each transfer of the mycelium to prevent senescence and maintain mycelial vigor. Five hundred milliliters of agar medium will fill around 20 standard petri dishes. See Appendix H for a list of agar recipes.

Preparing and Sterilizing Agar

After an agar recipe has been selected, place the ingredients in a pot over low-medium heat. Heat the media to the point that the ingredients have just melted as much as possible. Do not boil the media as this can create caramelized sugars that are toxic to some fungi. If the agar does not fully dissolve on the stove with the sugars, it will in the PC.

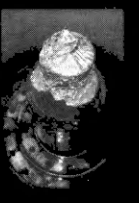
Once dissolved on the stove, the agar media is poured into a vessel for sterilization. At this point the cultivator has two options for how to sterilize and ultimately use the agar:

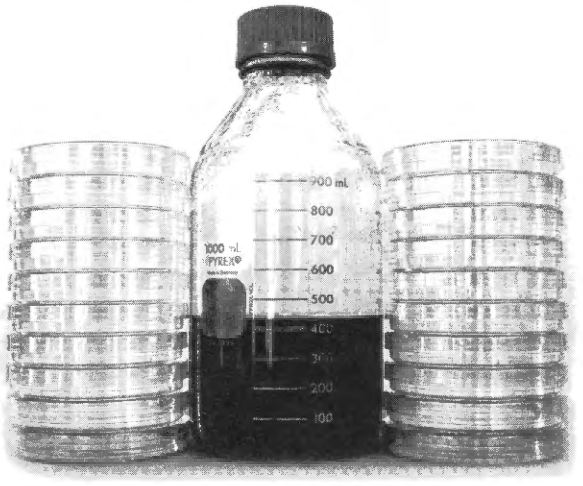
- **Prefilling small jars:** Shallow, small jars (such as those used for baby food) can be used as cheap, reusable containers for agar work. Media that has been dissolved on the stovetop is poured into these jars, a lid modified with a filter is attached, and the jars are then sterilized in the PC. Pre-poured jars work well for simple agar work because they avoid the stress and mess of pouring agar into petri dishes. The major drawback is that these jars take up more volume than petri dishes. It can also be more difficult to cleanly extract chucks of myceliated agar from these relatively tall and narrow containers.
- **Post-PC pouring:** More traditionally, agar media is pressure cooked in a large container and later poured into sterile petri dishes under aseptic conditions. This method of working with agar is more time consuming and contaminant prone than using pre-poured jars. However, it is the preferred option for any experimental work as the mycelium in petri dishes can readily be viewed and worked with more easily than when in the bottom of a relatively taller jar that has an opaque lid. Plates should not be poured and then pressure cooked as they tend to boil over during cooking and become unusable.

In either case, the agar is cooked at 15 psi for 30 minutes. Once pressure in the PC normalizes to 0 psi, pre-poured agar jars can be pulled out to cool. Once cooled, they can be inoculated or stored in a refrigerator for later use. If you plan to pour plates, the following procedure is recommended.

The Agar Vessel

Agar that will be poured should be cooked in a glass vessel that can withstand the high temperature and pressure environment of the PC. Pyrex flasks and/or long neck liquor bottles can be used. These should be stopped up with synthetic fiber stuffing and covered with aluminum foil if they do not have a heat tolerant cap.





Pouring Plates

Expensive, reusable glass petri dishes can be used instead of plastic dishes. These glass plates must be washed, dried, wrapped in aluminum foil, and sterilized prior to pouring. They can be sterilized either with the cooking agar in the PC or by being cooked at 250°F (121°C) in an oven for 30 minutes.

Some companies sell pre-poured sterile petri dishes, often with a very basic agar formulation.

Materials

- Agar vessel half-filled with sterile agar media
- Plate wrapping material
- Sterile petri dishes

Method

1. After cooking the agar, allow the PC to cool for two hours. Cooling for this long is recommended as it makes the agar vessel less painful to hold yet keeps the agar fluid enough to pour. Pouring agar that is cool also reduces the degree of condensation that tends to form on the inside of petri dish lids. Condensation is an undesirable effect that prohibits viewing of the mycelium and encourages contaminant growth.
2. Prepare your transfer space for aseptic work. Load your materials, cooled agar vessel, and any inoculum you are planning to work with once the plates are cooled and ready for use.
3. Optionally, add hydrogen peroxide to the agar, as described earlier.
4. If working with a sleeve of pre-sterilized plates, open the sleeve under aseptic conditions and form two stacks of plates. Set the plastic sleeve aside.
5. The agar should now be poured into each plate as quickly and cleanly as possible. Use an up-and-back motion when lifting plate lids for pouring. This specific movement helps avoid passing your fingers over the sterile field of a plate's interior while also reducing the available surface area that ambient spores and bacteria in the air may pass through to come into the plate. Avoid spilling agar on the outer surfaces of a plate's bottom half as this can create a path along which contaminants may enter the plate. I prefer to start pouring at the bottom of a 10-plate stack and work up from there. This helps transfer the heat up the stack and reduce the number of lids with heavy condensation. Once the two stacks are poured, I carefully move one stack on top of the other and cover the whole stack of 20 plates with the plastic sleeve that they initially came in. This stacking and insulating helps reduce condensation. Optionally, place a cup of hot water on top of the top plate to further reduce condensation on the upper plates.
6. Allow the plates to cool and solidify in the clean transfer space. This takes around 30–60 minutes.
7. Once firm, plates can be immediately inoculated under aseptic conditions or wrapped and refrigerated for long-term storage. Plates kept in cold storage are viable until they get contaminated or they dry out. Label the plates with the media recipe used or color code them with a permanent marker.
8. Optionally, put the plates in an incubator for 24–48 hours to see if contaminants appear. If these plates show high rates of contamination, the source must be identified. If contamination rates are low, congratulate yourself on mastering the challenges of pouring plates!

Wrapping Plates

Petri dishes should be sealed prior to being placed into storage or incubation. Parafilm™ is a microporous wax tape commonly used to seal plates. It allows for gas exchange while also preventing the entrance of microbes into a plate. Inoculated plates should only receive one layer of Parafilm; uninoculated plates should be double wrapped. Plastic cling wrap used for storing food can also be used to seal petri dishes. Gladwrap™ is the preferred brand for this cheaper route as it is microporous and thus allows for gas exchange. Other non-porous plastic wraps can be used as a cheap method to seal plates until later use. Plates double wrapped in Parafilm can be stored in a refrigerator for several months. After this time, the mycelium tends to overgrow the plate and/or dry out, impacting overall vigor.

Inoculating Plates

Once your plates are cooled, they are ready for inoculation. Plates can be inoculated with spores or mycelium, depending on the needs of the cultivator.

Spores

Working with spores is not a regular practice. Even when spores are obtained under the cleanest conditions, their use may produce more contaminated plates when compared to a culture of pure mycelium. Putting many spores on a petri dish also results in numerous spore combinations and distinct mycelial networks. Each of these spore combinations constitutes a unique strain that has its own genetic expression and cultivation potential, leaving the cultivator with the task of determining each strain's unique characteristics and viability for larger scale cultivation. This shotgun of strains is therefore not the best place to start general cultivation projects but is intentionally employed for the following reasons:

- To develop new strains for experimental purposes. This may include getting strains to self-select on an agar formulation that contains a chemical or novel substrate. Any strains that develop on this uncommon media are inherently capable of utilizing, or at least tolerating, the chemical compound or substance that has been added to the agar.
- The mycelial stock the cultivator has been working with is losing vigor. Spores from this slowing strain are harvested from a fruit body to develop an offspring strain with renewed vigor. Similarly, spores harvested from a mushroom grown on a novel substrate (such as chemically contaminated soil) may produce offspring with greater aptitude for growing on that substrate than its parent mushroom's mycelium. This is inheritance at its epigenetic finest.
- Spores are the only form of available inoculum.
- The grower doesn't want to fuss with worrying about strains and is happy to just grow mushrooms in some form.

Mycelium

There are several major reasons for working with tissue instead of spores as source inoculum:

- The strain being cloned is known to have desirable traits (e.g. high medicinal value or local adaptations). Cloning a fruit body also avoids the shotgun effect of spores, ensuring, for example, that the strain actually forms mushrooms, which some strains don't.
- Cloning a mushroom found growing off of an unusual substrate (e.g. pine wood or oil-saturated soil) suggests that the strain can be grown off that same substrate in the future.
- For the conservationist or researcher, cloning a mushroom or its mycelium is a means to preserving that strain's genetics.

I keep a stack of small pre-poured plates in the fridge at all times to facilitate immediate cloning of wild harvested mushrooms.

Sourcing Inoculum

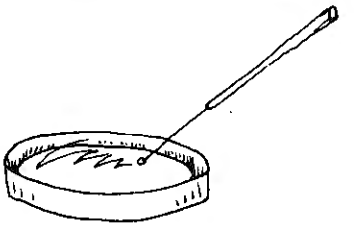
Spore Sources

- **Commercial:** Spore prints and syringes filled with spores suspended in water (spore syringes) can be ordered for many species. While ideally these are sold competitor-free, it should always be assumed that any work with spores can result in some initial degree of contamination.
- **Homemade:** Specifics on making your own spore prints and spore syringes for culture work are detailed later in this chapter.

Tissue Sources

- **Commercial cultures:** Myceliated petri dishes, liquid culture syringes, and slants of isolated cultures can be ordered from a wide variety of companies as an initial source of mycelium.
- **Commercial products:** Grain spawn, sawdust spawn, plug spawn, and other living, myceliated products can be cloned as initial inoculum sources.
- **Fresh or dry mushrooms and mycelium:** Mycelium removed from a piece of substrate or excised from the interior of a fruit body can work as inoculum.

Inoculating Plates With a Spore Print

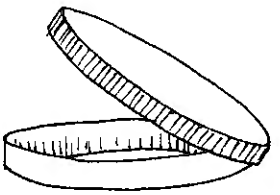


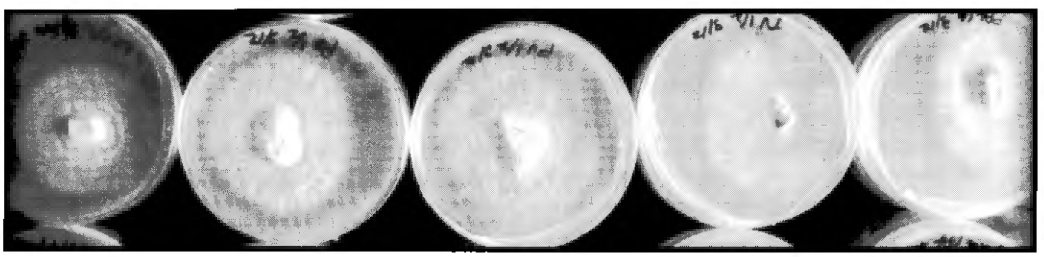
Materials

- 1 clean petri dish
- 1 clean spore print
- Inoculation loop
- Plate wrapping material
- Tool sterilizing materials

Method

1. Clean the transfer area and prepare to work under aseptic conditions.
2. If the petri dish was in cold storage, allow it warm to room temperature in the transfer space.
3. Unwrap the plate.
4. Open the spore print and sterilize the inoculation loop.
5. Open the petri dish like a clamshell and stick the hot inoculation loop tip into the agar to cool it off and to make it sticky with agar. Carefully pull the loop out of the plate without touching it to anything. Close the petri dish.
6. Wipe the loop across the spore mass to deposit spores on to the tool. If spores are visible, thousands of spores are likely on the tool.
7. Open the petri dish as minimally as possible and wipe the spores across the surface of the agar in a zig-zag pattern. Spread the spores.
8. Remove the tool.
9. Close and wrap the plate with a single layer of wrapping material.
10. Label the plate with species and date and place it in an incubator or spawn run space to initiate spore germination. Return the inoculum to storage.





Inoculating Plates With a Spore Syringe

Materials

- 1 clean petri dish
- 1 spore syringe that has been in cold storage and not exposed to excessive heat
- Plate wrapping materials
- Tool sterilizing materials

Method

1. Follow steps 1–3 for *Inoculating Plates With a Spore Print.*
2. Expose the spore syringe's needle and sterilize the needle tip using a heat source. Squirt a small amount of liquid out to cool the needle. A hot needle can destroy spores. Flick the syringe with your finger to disperse the spores inside of the syringe.
3. Use the clamshell method to open the plate and insert the needle tip without touching any of the plate's surfaces. Deposit 1–3 drops of spore water on to the surface of the agar. Remove the needle without touching anything and close the lid.
4. Place the lid back on the needle.
5. Swirl the plate around to spread the spores.
6. Follow steps 9–10 for *Inoculating Plates With a Spore Print.*

Heat Sources for Sterilizing Tools

Tools must be sterilized prior to every transfer of spores or mycelium. Two sterilizing tools are commonly employed by cultivators:

- **Bacti-Cinerator™:** Designed specifically for sterilizing tools used in microbiology, this electric heat source is ideal for working with agar. These devices can often be found used through online auction sites for around US$50.
- **Alcohol flame/Torch lighter:** To sterilize a tool with these heat sources, first dip it in a jar containing alcohol, then run the tool through a flame to burn off the alcohol. Though inexpensive, I find these options not as reliable, safe, and easy to use as a Bacti-Cinerator™. Flames also go out after prolonged use in a glove box where oxygen supply is limited.

Spore Germination and Strain Selection

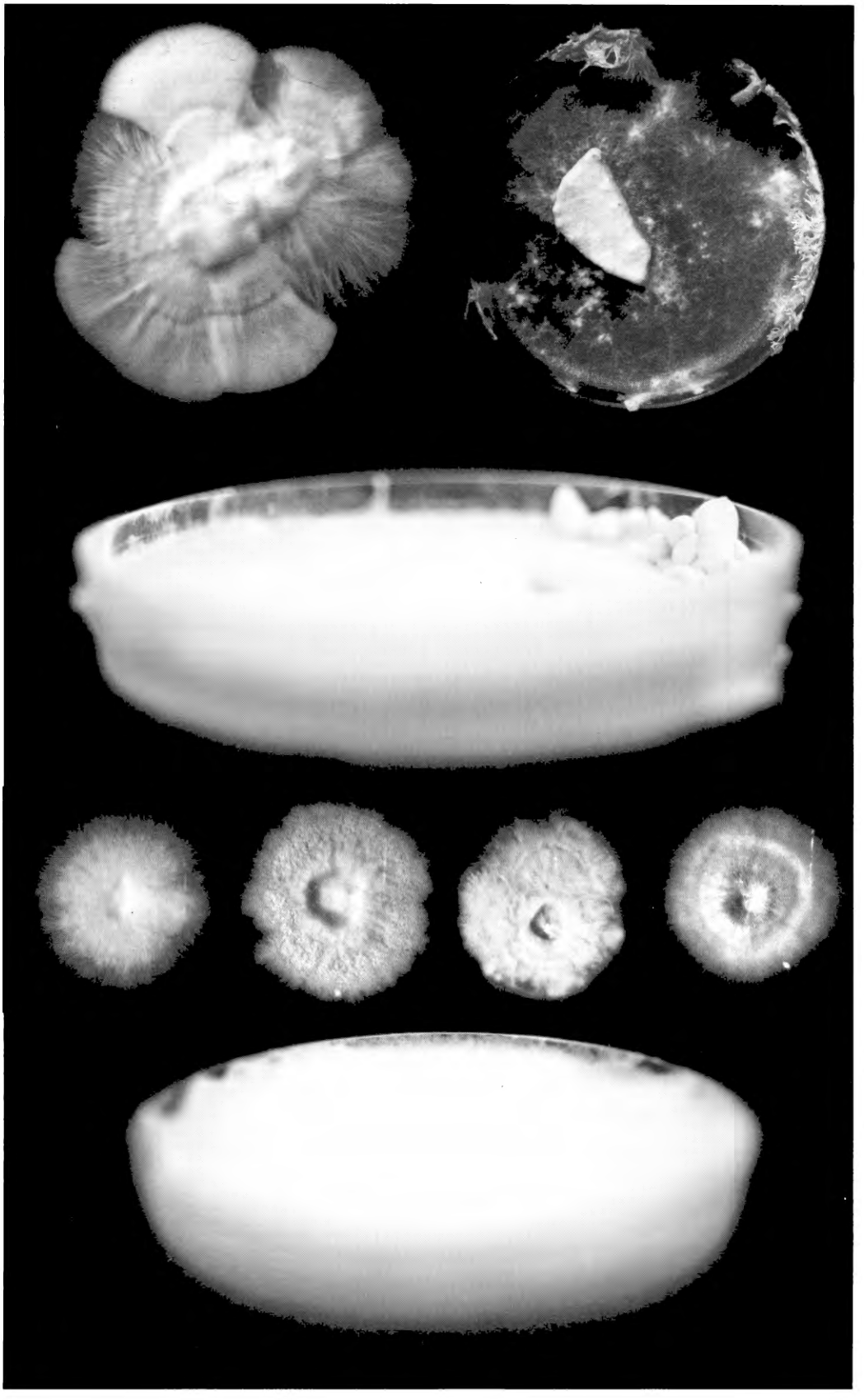
In several days, visible areas of mycelium should appear on the plate as spores begin to germinate and mate. Distinct sectors will be apparent, each being a different strain. Some of these mycelial networks will have very different appearances from the others, while otherwise similar looking areas will "butt up" against each other and form boundary ridges, signifying incompatibility.

The constellation of strains covering the petri dish can be used together as an inoculum for the grains in Stage 2. When these grains are later used as inoculum in Stage 3, the mushrooms that ultimately fruit in Stage 4 will likely produce uneven yields across the fruiting substrate, reflecting the blend of strains. If one sector on the fruiting substrate produces a good yield, a mushroom from this area can be cloned (discussed later). This is a simple means for designating a strain that is preferable for a given substrate formula or fruiting environment.

A more focused approach to strain development is to separate each of the strains from the initial petri dish using a Plate-to-Plate Transfer (described later). Once each strain is isolated on individual plates, some tissue should be backed up for later use, also discussed later. Once backed up, each strain should then be run through the entire cultivation process. During this process the cultivator must take careful notes on the various traits of each strain. One to three months later, once the strains have fruited and notes can be compared, the cultivator then returns to the backup of the top-performing strain and works with this culture in future endeavors. Typical factors for assessing strains are noted to the side.

Strain Selection Traits

- *Recovery time from transfers or shaking.*
- *Quality of mycelium.*
- *Adaptability to substrates.*
- *Dependence on microflora.*
- *Time from inoculation to fruiting.*
- *Duration between flushes.*
- *Temperature and cold shock requirements.*
- *Number of primoria formed and percentage that mature.*
- *Medicinal quality of mycelium and mushrooms.*
- *Ability to degrade toxins.*
- *Antimicrobial activity.*
- *Appearance, flavor, texture, aroma, nutritional profile, and shelf life of mushrooms.*



(Top Left) Various strains arise after the germination of spores. Sectors are demarked by visible differences as well as ridges.

*(Top right) The nerual-like mycelium of Lion's Mane (*Hericium erinaceus*) fruiting on the plate.*

*(Middle top) King Oyster (*Pleurotus eryngii*) fruiting on the plate.*

(Middle bottom) Differing mycelium formation patterns and qualities between four species.

(Bottom) The thick, cloud-like mycelium of Cordyceps sinensis.

Inoculating Plates With Mycelium

From a single mycelial cell—fresh or dried— thousands of pounds of edible and medicinal mushrooms can be cultivated over the course of just a few months. This explosive growth potential is an outcome of the totipotent, holographic nature of mycelium. To unpack this concept, the first skills to learn are how to work with a piece of an existing strain's mycelium as a source of genetics to create inoculum.

Cloning Fresh Mushrooms

One of the most common ways to clone a strain is to cut a small piece of tissue from the interior of a fruit body and then place it inside of a petri dish under aseptic conditions. Within days, this tissue will usually revert back to a vegetative state and begin to myceliate the plate. This is time slipping backwards through fungal cultivation.

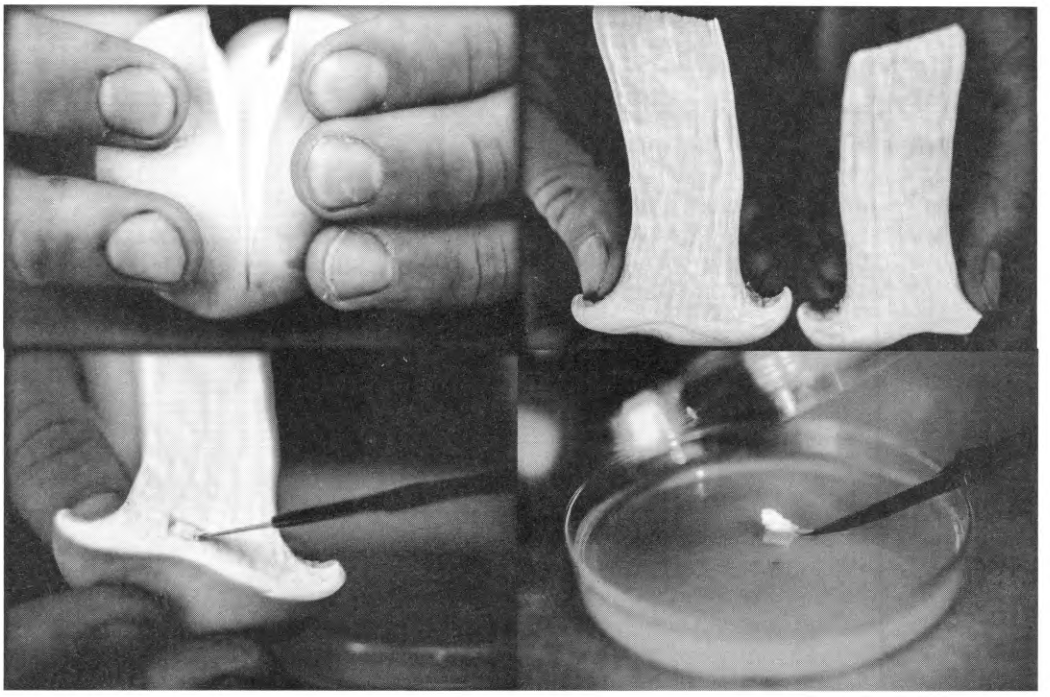
Materials

- 1 fresh, young mushroom
- 1 clean petri dish
- Alcohol wipe
- Knief, scalpel, or set of tweezers
- Plate wrapping material
- Tool sterilizing materials

Method

1. Follow steps 1–3 for *Inoculating Plates with a Spore Print*.
2. Wipe the mushroom cap down with alcohol.
3. Flame sterilize your large knife and make a shallow cut in the center of the mushroom cap to open the mushroom. This cut likely pushes contaminants into the mushroom tissue, thus the cut should be shallow and tissue should not be cloned from where the knife entered.
4. Set the knife down and open the mushroom like a book, exposing the sterile tissue inside. Keep your hands under the mushroom and do not pass your hand over the inner tissue of the mushroom. Alternately, tear open the mushroom if that is easier.
5. Sterilize your scalpel or tweezers and wait several seconds for it to cool.
6. Excise a small piece of mushroom tissue from either just above the gills (but not the gills themselves), the cap interior, or the stem interior. These are areas where cells are rapidly elongating and growth is active. With some species it may be difficult to pull tissue from anywhere on the mushroom. Do your best.
7. Optionally, once the tissue is excised, dip it in a small dish of 3% food grade hydrogen peroxide for 5–10 seconds to clean its surface. Many wild harvested mushrooms contain bacteria that interfere with current cultivation protocols. In reality, these microbes are likely somewhat beneficial to the fungus, hence their presence. This cleaning process is recommended for wild, woody, and/or thin-fleshed mushrooms and/or their mycelium cloned from wood chips, cardboard, or other naturalized substrates.
8. Quickly open the petri dish and place the mushroom tissue on the agar. Mycelium tends to stick to tools. A good technique to easily remove tissue from a tool is to cut through the mycelium and into the agar, then slide the tool back and through the agar, leaving the mycelium behind.
9. Optionally, repeat steps 5–8 two more times on the same plate to ensure that you obtain at least one clone that will regenerate without contamination. I prefer to use smaller petri dishes for cloning, so as to conserve agar.
10. Wrap the plate once, label it with species, strain (or harvest location), and date, and place it in an incubator or in a warm space to encourage rapid myceliation. Regrowth should be visible within a week.

A variety of culturing tools. Different fruit bodies have different densities and textures, making some tools preferable over others. I keep several in the transfer space. For woody mushrooms, try scraping with a sharp sterile scalpel and then plucking up the tissue with tweezers.

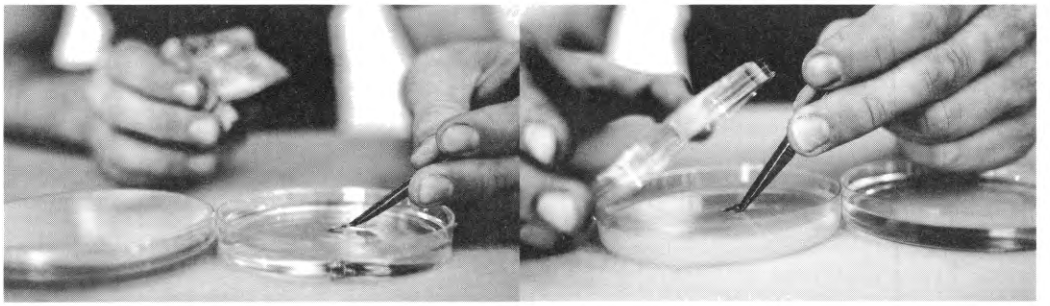


After exposing the inner tissue, the hands never pass over the inside of the mushroom. Healthy tissue is removed with a clean tool and placed on a plate by cutting through it and pulling back.

Cloning Dry Mushrooms or Mycelium

Exemplifying the incredible resiliency of fungi, mycelium that has been thoroughly dried for weeks, months, or decades can be reanimated to become a vigorous and viable culture for cultivation. The cloning process for dried tissue is nearly identical to that for fresh mushrooms. The only difference is that, in my experience, the soak in hydrogen peroxide tissue is not optional and should be done for 10–60 seconds. The soak not only cleans the tissue, it also rehydrates it. Shorter soak times are preferred as the peroxide can stunt the mycelium, although longer soaking provides for increased hydration. Optionally, soak the tissue in sterile water before dipping it in hydrogen peroxide.

Dried mycelium can take a long time to regenerate. I once cloned a sun baked Amadou conk that had been harvested a year prior. Two weeks later, I almost tossed the plate as no activity was visible. Luckily I didn't do this as the mushroom eventually awoke on week three, spiraling across the plate with a new-found burst of life.



Cloning a Commercial Product

Commercial grain, sawdust, or plug spawn can be used as a viable strain source. The process is essentially the same as for cloning a fresh mushroom except here the mycelium of the spawn is used as the tissue source. The best practice for cloning spawn would be to open the culture in the clean transfer space and, working as aseptically and quickly as possible, remove a piece of tissue with a scalpel or pair of tweezers and put it in a clean petri dish. Commercial strains may be senesced due to their time spent under aseptic conditions.

Plate-to-Plate Transfer

Once a plate is well myceliated, pieces of the tissue are then moved to storage, another substrate, or to another plate. Plate-to-Plate Transfers are generally done for the following reasons:

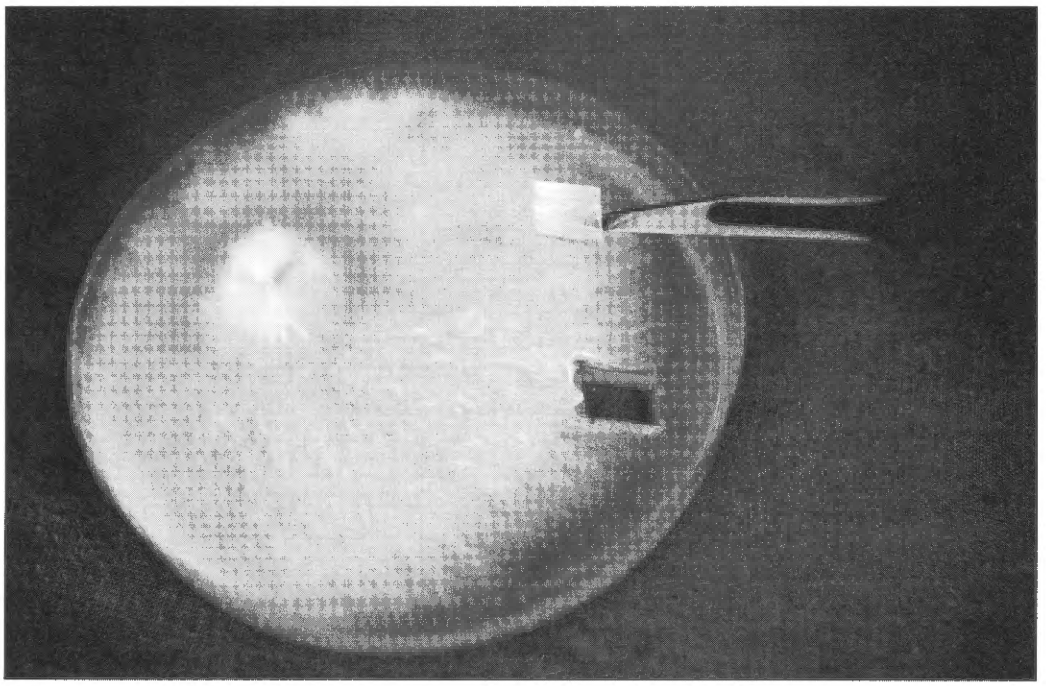
- To deal with contaminants, discussed soon.
- To expand the mycelium from one plate to many, thereby bulking up the amount of mycelium. These numerous plates, once myceliated, are then used as inoculum, stored for later use, or sold/traded.
- To test the response of a given species/strain to different concentrations of chemicals mixed into the agar or placed on the agar surface.

Materials

- 1 clean petri dish
- 1 petri dish two-thirds covered in mycelium
- Plate wrapping material
- Scalpel or miniature metal spatula
- Tool sterilizing material

Method

1. Under aseptic conditions unwrap both plates.
2. Sterilize your tool with a heat source.
3. Clamshell the fresh plate open and stick the tool in the agar to cool it. Remove the tool without touching anything and close the plate.
4. Clamshell the myceliated plate open and cut out a piece of mycelium roughly 1 cm^2 from the leading edge of the culture. Use the tool to lift up the agar piece and remove it from the plate. Take care not to disturb the mycelium too much as it is already being shocked from the cut. Close the plate.
5. Clamshell the fresh plate open and place this myceliated agar piece into the plate, mycelium side up.
6. Remove the tool without touching anything. Close the plate, wrap it, label with date and species/strain, and place it in the incubation space.



Culture from the leading edge.

Cardboard for Culture Collection

Considered by some as the poor human's petri dish, plain old cardboard works surprisingly well as a horizontal platform for germinating spores or cloning tissue. Being low in the nutrients required by most competitor microbes and fungi, this cellulose-rich material is a contaminant-resistant and selective substrate for many commonly cultivated decomposer mushrooms.

To germinate spores, the thin grey cardboard commonly used for food packaging is ideal. Hydrate this cardboard by soaking it in water for 10–30 minutes then allow it to drip dry. Adding dextrose to the soak water at a 4% concentration helps support germination. Place the cardboard into a jar and sterilize it at 15 psi for 15 minutes. Once cool, introduce spores under aseptic conditions. Strains will develop in several days. As you are working with spores, there may be invisible contaminants present on the cardboard.

An even simpler means for using cardboard as a substrate is in the cloning of a mushroom or its mycelium. Here, corrugated cardboard has been found to be a superior material due to its starch-based glue and the aerating undulations of its textured design.

Materials

- Mushroom pieces (stem bottoms and attached mycelial strands are preferred, but other parts of the mushroom also work)
- Optional coffee grounds or moistened sawdust
- Plastic container or bag
- Tape- and ink-free cardboard from the United States or Canada

Method

1. Soak the cardboard in hot water until it is thoroughly saturated (roughly 30–60 minutes).
2. Remove the cardboard from the water and let the excess water drip off.
3. Remove one side of the cardboard, exposing its inner corrugations.
4. Evenly disperse your fungus throughout the cardboard, placing pieces about 3 inches (7.5 cm) apart in all directions.
5. On top of this fungus, place another layer of saturated corrugation and backing such that the fungus is sandwiched between two layers of corrugation.
6. Roll up the sandwich to provide a slight pressure on the mycelium. Alternately, sandwich it flat and, once bagged, place a book on top of the bag to apply a slight pressure.
7. Store the roll in a dark, warmish place where it will get air exchange, retain its humidity, and not dry out. Plastic sandwich bags or food storage containers work well.
8. Circulate the air in the container at least once daily and spray with water as needed to keep the cardboard moist.
9. In several days or weeks, the mycelium should be visible on the cardboard.

This technique is great for cloning wild mushrooms, especially when on an extended trip. Once the mycelium is actively growing, experience has shown that it should soon be moved on to another, more nutritious food source as soon as possible. As this cloning method is generally not done under aseptic conditions, the myceliated cardboard can't be directly used as inoculum for sterile substrates. Instead, it can be applied in low-tech and/or outdoor projects. Generally, cardboard spawn is slower to work with outdoors when compared to the mass inoculation potential provided by sawdust spawn production.

As far as I have been able to determine, the jury is out on the general safety of cardboard glue in general or as a substrate. While cornstarch is reportedly the primary ingredient, the recipes are proprietary information and other chemicals may be present, regardless of the country of origin.

Cardboard-to-Plate Transfer

Some wild mushrooms will myceliate on cardboard more readily than on a petri dish, perhaps due to the presence of beneficial bacteria. So, in addition to cloning a wild mushroom on agar dishes, I also clone most species on cardboard. This low-tech method for getting mycelium growing is cheap and easy but does not allow for a clean or well-fed backup of the culture. To isolate the culture, pieces of the mycelium can be transferred to a petri dish for further cleaning and isolation

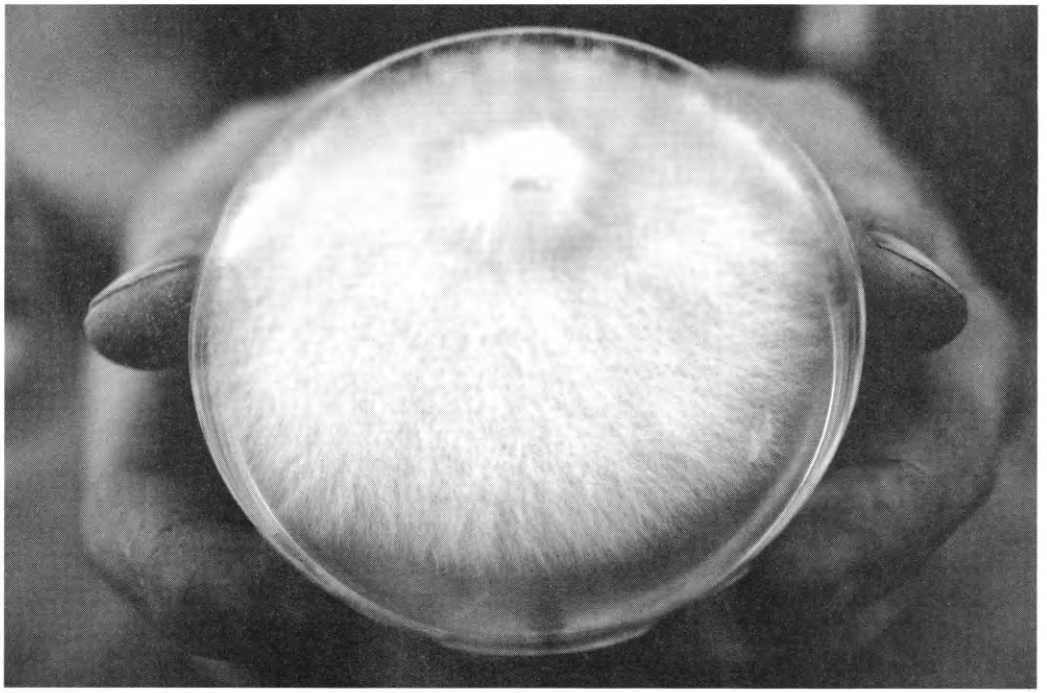
using the cloning techniques that use hydrogen peroxide, as described earlier. This method works quite well for fresh and dried mycelium. I have repeatedly reanimated mycelium that had dried out six months earlier on a forgotten piece of cardboard. Amazing feats like that are what keep me fascinated by fungi.

Dealing With Contaminants on Plates

Whether you are working with spores or tissue, hopefully you will soon see pure white mycelium growing several days after inoculation. However, it is also likely that you might see bacterial or fungal contaminants arising as well, especially if an antibiotic was not incorporated into the agar at pouring. Luckily there are several options for dealing with these inevitable moments:

- **Cut out a piece of clean mycelium and transfer it to a new plate:** This process is known as *subculturing* or *subbing*. This second plate might also develop the contaminant, as the transferred piece may be "dirty." A third (and hopefully) final sub might be needed to obtain a clean culture.
- **If possible, cut out the contaminant:** Most molds produce white mycelium during their initial growth. If the cultivator learns to recognize these colonies as competitors, they can be cut out and removed from the plate. If the mold has gone to spore (i.e. the mycelium has taken on a distinct color), attempting to remove the mold might shake more mold spores around the plate. Subbing is then preferred.
- **Cover the mycelium and contaminant in hot agar:** Just like it sounds. The mycelium will likely climb up through this new layer faster than the mold. The mushroom can then be easily subbed. Alternately, when you clone a mushroom, flip over a piece of the plate's agar to cover the clone from the start. This can help leave behind contaminants that may appear.
- **Use antibiotic agar to kill off bacteria:** Place a fresh piece of antibiotic agar from another plate on top of the contaminant in a manner similar to a Plate-to-Plate Transfer. Under this antibiotic agar, the microbe will die and the mushroom mycelium will continue to grow.
- **Do nothing:** Often, the microbial war that develops on the plate between fungus and foe will result in the mushroom mycelium effectively combating the contaminant. Watching this process unfold is in itself a great learning opportunity and glimpse into the habits of the mushroom. If the mushroom overtakes the contaminant, the mycelium should not be used as an inoculum for aseptic cultivation. It should still be subcultured to ensure that a clean culture is obtained.

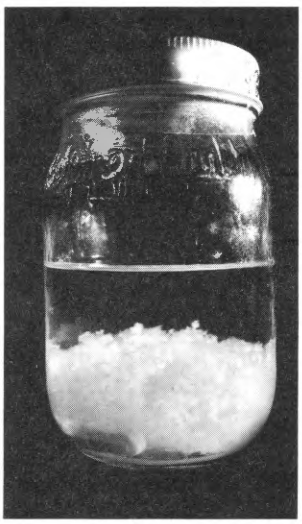
You can learn a lot about the quality of your transfer technique by observing where contaminants appear on the plate. If a contaminant shows up on the edge of the plate, it may have entered during the tissue transfer, during pouring and wrapping, or during storage. If the competitor shows up on or near where the mycelium was transferred, your mycelium or tool may have been dirty.



Liquid Culture

Considering the benefits of liquid-based fungal cultivation detailed in Chapters 3 and 7, home cultivators have long attempted to scale industrial submerged fermentation techniques down to a kitchen-level protocol. Despite many attempts, it wasn't until the founder of the web forum Mycotopia, Hippie3, developed the airport lid in 2005[14] that the many benefits of this cultivation technique became readily accessible. It is my opinion that this simple lid design is one of the greatest advancements in home mycology of the last two decades. With this simple tool, the benefits of cultivating fungi are immediately released from the costs and complexity of agar work. These little blobs of silicone and their twinned air filters are the keys to making high yield mushroom cultivation accessible for people of all backgrounds and budgets around the world. Consider the following benefits that a liquid-based culture offers:

- **Liquid culture is cheap:** No agar is needed, simple ingredients are used. The jars, lids, and syringes used in the process are all reusable. Liquid culture broths can be sterilized in a hot water bath, avoiding the need for a pressure cooker.
- **Liquid culture is time efficient:** There is no need to cook and cool agar for hours and none of the stress and mess of pouring plates. Once a healthy mother jar of LC is established, it can serve as inoculum for many months, essentially eliminating the need for constantly starting mycelial lineages with agar plates.
- **Liquid culture increases myceliation rates:** Mycelium in a liquid suspension can grow three-dimensionally, increasing growth rates when compared to the two-dimensional surface of an agar plate. When LC is aerated, the mycelial network breaks into a constellation of fragments, each with its own array of active hyphal tips. This is significant as, compared to an agar plate where the mycelium is only active at the edge of a single colony, liquid culture inoculum is almost entirely comprised of leading edge mycelium.
- **Liquid culture inoculation rates are high:** Liquid culture is sprayed onto substrates with a syringe. As the medium percolates through the substrate, the individual mycelial clusters distribute throughout the material to explode with growth at each point of contact. The result is a much more even distribution of inoculum than that achieved by a piece or two of myceliated agar.



THE TWO MAIN DRAWBACKS OF LC

CONTAMINATION: *It can sometimes be hard to tell if an LC is contaminated. If an LC is contaminated, it is very difficult (if not impossible) to clean it up. Thus, LC requires a modest amount of care when handling and inoculating.*

STRAIN DEVELOPMENT: *It is not easy to witness strain development in a liquid culture. When inoculated with spores, it is not possible to isolate strains from a liquid culture jar. Further, using spores in liquid media is not recommended due to the high risk of contamination.*

- **LIQUID CULTURE WORK CAN BE DONE ANYWHERE:** Using a syringe and airport lid, one can transfer mycelium to grain jars outside of an aseptic transfer space. Whole mushrooms can also be cloned in the open air using this method. This reduces the need for constantly preparing and maintaining a dedicated transfer space. This is perhaps the greatest benefit of this method over the many annoyances and costs associated with agar work. The ability to grow grain spawn in the absence of a clean transfer space using liquid culture inoculum quickly translates to any home mycologist becoming a mushroom farmer. With this challenging step overcome, time and energy increases in supply, allowing for creativity to spur new applications for cultivation beyond the practices of food and medicine production. Liquid culture allows us to work, think, and grow outside the glove box. How will you work with its many benefits?

For all of these reasons, LC is my preferred inoculum for everyday use. Never again will I go back to working with agar for general inoculations. There is no point.

Liquid Culture Recipes

Various liquid media formulas have been developed for the home cultivator; the most common are listed in Appendix H. While these recipes are great starting places for inoculum production, there are several points to consider if you wish to elaborate upon them. The most important are that a proper carbon source (typically a sugar) is used and that its concentration is no more than 4% of the entire formula (e.g. 4 grams of sugar per 96 milliliters of water). Though barely sweet to the human tongue, this is the maximum sugar load that most cultivated mushroom species can tolerate. Household sugar (sucrose) is not preferred and dextrose shouldn't be used as a singular carbon source. Additional nutrients such as peptone, gypsum, and various flours can be added as well. These additives can make the resulting broth a bit cloudy, making it harder for a beginner to recognize contamination. As with agar formulas, adding a small amount of the final fruiting substrate (or tea made from that substrate) can help facilitate increased myceliation later in the cultivation process.

Just as with fruiting substrate formulation, numerous experiments have been conducted to determine the proper liquid media recipe—per species/strain—that will facilitate the greatest production of medicinal products or industrial enzymes during the fermentation process.

Sterilizing Liquid Media

MATERIALS

- Aluminum foil
- Clean jars with airport lids
- Liquid media ingredients
- Stir bar or other agitator

METHOD

1. Mix and dissolve ingredients in a pot over low-medium heat.
2. Once dissolved, fill a clean jar (or multiple jars) half-full with the solution.
3. Place a couple of marbles, a piece of broken glass, a crystal, a magnetic nail with its head cut off, or a magnetic stir bar in the jar.
4. Place an airport lid on each jar and cover them with aluminum foil.
5. Pressure cook the jar(s) at 15 psi for 15–20 minutes.
6. Once the pressure has reached 0 psi, the jars can be removed and allowed to cool. Alternately, allow the jars to cool inside the pressure cooker overnight.

If you do not own a pressure cooker, boiling is an alternative means for sterilizing liquid media. Place the jars in a pot of cold water, at least half way submerged in the water. Bring the water up to a boil, boil the jars for 30 minutes, and then allow them to cool before using. Be sure to run a blank jar with this method to confirm that you are effectively sterilizing the media.

Inoculating Liquid Media by Cloning

The following are the two main ways that I prefer to inoculate liquid media. I only clone mycelium to LC—I never use spores. This is because the liquid media is a blank slate of sterile, nutrient-rich water—the optimal growing medium for many competitors. If a single mold spore or bacterium enters the jar...*c'est la vie.*

A fresh mushroom can be directly cloned into liquid media outside of an aseptic transfer space. In essence, a biopsy of a mushroom is taken with a syringe needle and injected through the lid's airport.

Materials

- 1 airport jar, half-filled with freshly prepared liquid media
- 1 airport jar, half-filled with water
- 1 fresh mushroom
- 1 syringe with a 16-gauge Luer-Lok needle
- Alcohol wipe or cotton ball and alcohol spray
- Aluminum foil
- Tool sterilizing materials

Method

1. Wrap the syringe and needle in aluminum foil. Cover both jar lids in foil. The foil prevents the filter from getting wet in the pressure cooker, which can lead to contamination problems later. Pressure cook both jars and the syringe at 15 psi for 15–20 minutes. Allow to cool.
2. During the cooking process oxygen was depleted from the liquid media and now needs to be reintroduced. This can be done using the methods described in the section *The Growth and Aeration of a Liquid Culture*, below.
3. Wipe both injection sites with an alcohol wipe or alcohol-sprayed cotton ball. Clean the sites well but avoid excessive force as this may dislodge the silicone, enabling contaminants to enter the jar. Spray both silicone sites with alcohol.
4. Unwrap the syringe and draw up 5 milliliters of the sterilized water. Alternately, fill the syringes with water, wrap them with aluminum foil, and sterilize them with the LC.
5. Wipe the mushroom stem or cap thoroughly with alcohol, spray the mushroom with alcohol and then insert the needle through the stem or cap. Or just tear it open and stab a clean piece of inner tissue.
6. Remove the needle and check to see if there is tissue in the needle shaft. If there is not visible tissue, stab the mushroom again. Repeat until tissue remains in the needle shaft once it is removed from the mushroom. Try to be quick and avoid breathing on the needle.
7. Spray the LC jar port with alcohol again and insert the needle into the LC jar. Inject the piece of mycelium.
8. Label and date the jar and place it in the incubation space.
9. Optionally, consider sterilizing and inoculating multiple LC mother jars at once. This will help ensure greater success in the event that one of the jars becomes contaminated.

Cloning a mushroom. Note the small piece of tissue in the shaft of the needle.

Inoculating Liquid Media With Myceliated Agar

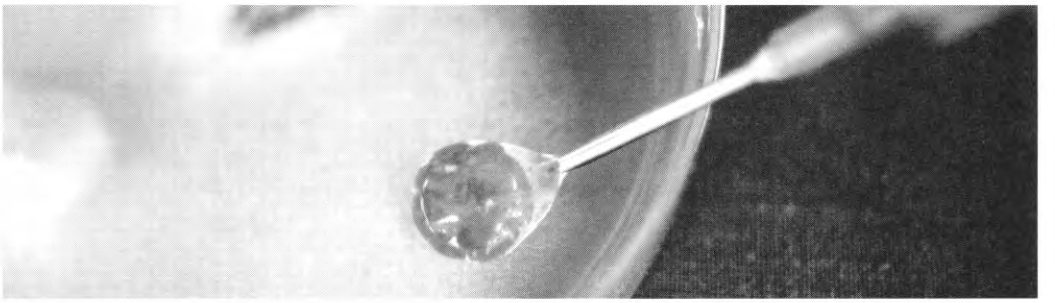
If the mushroom was harvested from the wild there is an increased chance of bacterial contamination, suggesting the above technique should be avoided. A more refined technique for inoculating LC is to use healthy and competitor-free mycelium from an agar plate. While this method must be done in an aseptic transfer space, it is preferred due to its high degree of success.

Materials

- 1 airport jar, half-filled with freshly prepared liquid media
- 1 airport jar, half-filled with sterilized water
- 1 myceliated, clean petri dish
- 1 syringe with a 16-gauge Luer-Lok needle
- Alcohol wipe or cotton ball and alcohol spray
- Aluminum foil
- Tool sterilizing materials

Method

1. Follow steps 1–4 for *Inoculating Liquid Media by Cloning.*
2. In your transfer space, unwrap and open the myceliated agar plate. Quickly, and without touching any petri dish surfaces with the needle, point the opening of the needle down and inject 1 milliliter of sterile water onto a small portion of the leading edge of the mycelial mat.
3. Using the needle tip, scratch some of the mycelium off the agar, suspending it in the sterile water. Quickly and cleanly suck up as much mycelium and water as possible.
4. Spray the silicone port on the liquid media jar with alcohol and inject the mycelium water into the media jar.
5. Label and date the jar and place it in the incubation space.



Only a small drop is needed to suspend the mycelium that has been scratched off. From these few cells, vast mycelial lineages will be spawned to create food and medicine, as well as greater autonomy in the cultivator.

The Growth and Aeration of a Liquid Culture

Once the liquid medium is inoculated, I tend to let the jar sit undisturbed for 3–4 days, during which time the mycelium begins to recover from the shock of being transferred and/or revert to vegetative growth. At this point the mycelium should begin to appear as a small cloud of tissue. As this network continues to grow it will begin to consume the dissolved oxygen in the liquid. If this oxygen is not replenished, the mycelium may suffocate and rise to the surface of the liquid in search of air. Thus, it is recommended to oxygenate liquid culture jars frequently. To provide a constant supply of fresh oxygen to the mycelium and thereby increase growth rates, agitate the liquid to break up the surface tension of the water and allow oxygen to dissolve in the liquid. This agitation also breaks up the mycelium as it grows, thereby increasing growth rates and enabling easy extraction.

Some cultivators blend a myceliated agar plate in an expensive, autoclavable, Erbach™ blender filled with water to create a liquid inoculum. I do not pursue this route as it incurs additional costs and sterility measures that I find unnecessary when compared to the elegance of the airport lid.

If you are only working with a small number of liquid culture jars, an easy means to oxygenating jars is to simply swirl them by hand to create a strong vortex in the liquid. A marble, crystal, or piece of glass added to the jar before sterilization helps with this breaking of the mycelium. Take care to not get the lid's filter wet as this can enable contaminants to enter the jar. A more efficient method of oxygenating and breaking up a liquid culture is with a speed-controlled magnetic stir plate, such as those described in Chapter 6.

Liquid-to-Liquid Transfer

Once a contaminant-free jar of liquid culture is established, it can be expanded to more jars.

I reuse my syringes and needles until they break. I tend to have a plastic bag filled with used and unused syringes. The sterile, unused ones stay wrapped in foil, while the used ones are unwrapped. Once I have used all the syringes and needles, I wrap them in foil and sterilize them at 15 psi for 15 minutes, often with a batch of liquid media jars.

Materials

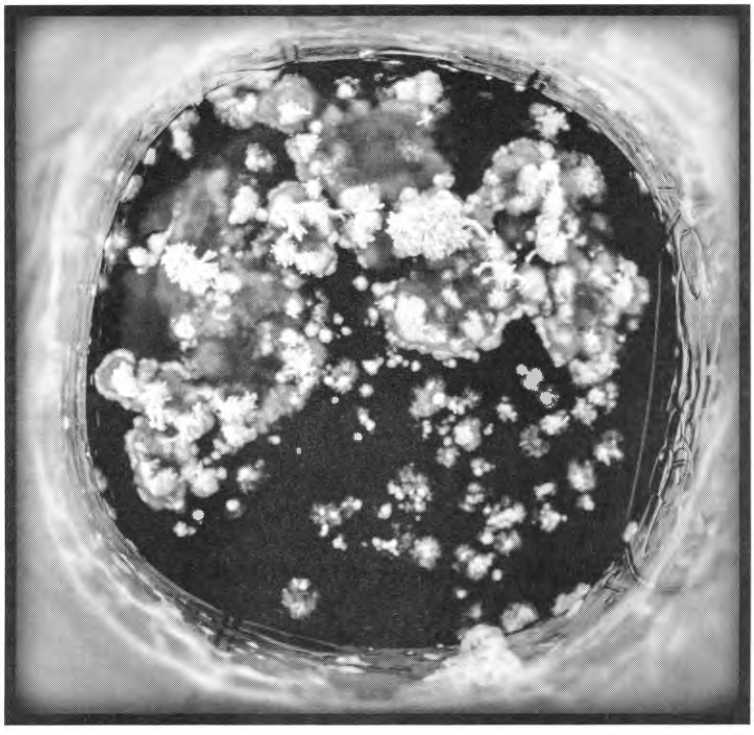
- 1 healthy, myceliated LC jar
- 1 sterilized non-myceliated jar of liquid media
- 1 syringe with a 16-gauge Luer-Lok needle
- Alcohol wipe and/or sterilization materials

Method

1. Follow steps 1–3 for *Inoculating Liquid Media by Cloning*.
2. Insert the needle into the myceliated jar, drawing out 2–10 milliliters of mycelium-rich LC. Be sure to check and confirm that you are drawing out mycelium and not just the broth.
3. Insert the needle into the fresh liquid media jar and inject the myceliated LC to the fresh jar.
4. Label and date the jar and place in your incubation space.

Recognizing Contaminants in Liquid Culture

As noted, liquid culture jars readily contaminate if not handled properly. The biggest risks come during injection and extraction. When an LC jar is contaminated by yeast or bacteria, the normally transparent broth will become milky or cloudy, prohibiting the ability to see though the jar. If a mold-contaminated jar is not agitated for several days, a mold colony will develop on the surface of the liquid. Ensure that this is actually mold and not the mushroom's mycelium by waiting to see if colored spores develop. Rarely, I have had what appeared to be non-contamined LC turn out to be a mixed culture of molds, yeasts, and mushroom mycelium when it was applied to grains. In these instances, it is likely that the mushroom mycelium was suppressing the growth of these other fungi inside the liquid. Some LC recipes produce precipitated sugar crystals after sterilization that can be easily mistaken for contaminants. These sugar crystals will eventually be consumed by the mycelium and are not a problem.

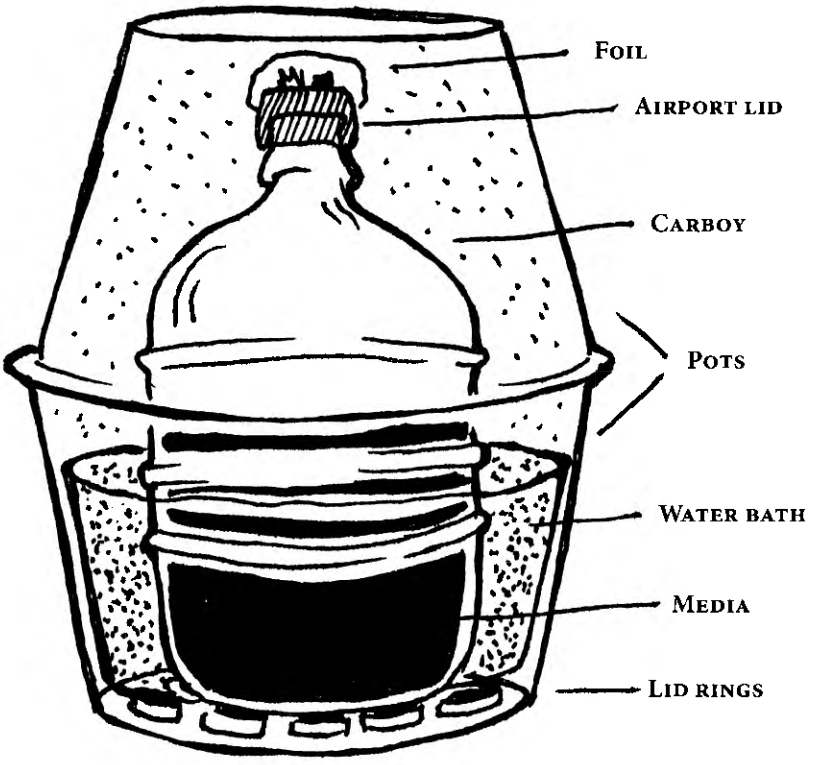


If not stored or maintained properly, some species will fruit directly on the surface of a liquid media. Here, Lion's Mane (Hericium erinaceus) arises due to lack of agitation. Liquid culture jars can be stored in a fridge for 6–12 months (or longer). Over time the mycelium may consume all of the nutrients, yet retain significant vigor. This may be due to it entering a state of suspended animation, similar to that obtained through the use of sterile distilled water, described later. I have inoculated grains with liquid inoculum that was a year and a half old without noticing any loss in vigor.

Scaling Up

While most small-scale cultivators use quart or half-gallon sized jars for producing liquid inoculum, the above concepts and techniques can easily be scaled to larger sized vessels such as a glass carboy used for beer and wine making. Such a container would need to be tyndallized in the absence of a large autoclave or pressure cooker. Mass mycelial fermentation is a common practice in large-scale mushroom cultivation practices, especially those focused on medicinal extractions or enzyme production. In these industries, 10–30-foot (3–9 m) tall stainless steel "fermentation reactors" are used to grow thousands of gallons of mycelium. These large operations require significant engineering to monitor sterility, oxygen levels, and other determinants of success.

These larger operations often seek to produce large quantities of pure mycelium and/or to extract fungal metabolites that have been exuded into the broth portion of the ferment. Following the scalability of cultivation, these industrial processes can be translated down to home- and community-scale production levels to create high quality medicinal products or collect enzymes, as detailed in Chapters 3, 7, and 10.



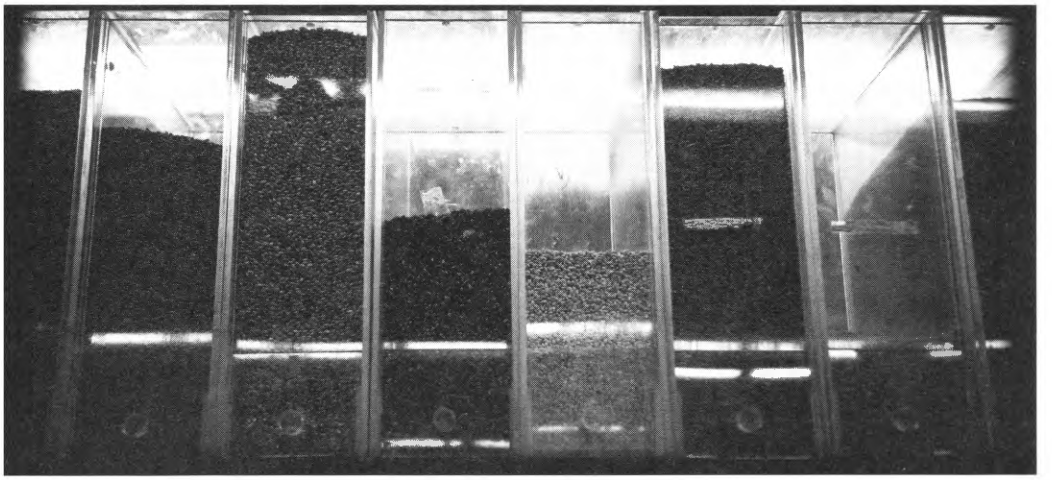
When is Inoculum Ready for Stage 2?

Agar based inoculum should be moved to another plate or to sterilized grains once the plate is 80–90% covered. Do not allow the mycelium to overrun the plate or hit the plate's edge as this might stunt the mycelium's growth or welcome uninvited guests. Liquid inoculum is ready to inoculate grains or other substrates as soon as viable mycelium can be extracted, generally after a week or two. I tend to incubate LC jars for 3–4 weeks prior to working with them so as to create a denser inoculum. Once an LC jar is around 30–50% myceliated, I put it in the fridge to slow further growth.

Stage 2: Grain Spawn

Once you have established some healthy, vigorous, and competitor-free inoculum, the next step is toward cooked, sterilized grains. As most species will not fruit on pure grains, this is an intermediary step for fruit body production. However, it is recommended as grains provide a cheap, nutrient-dense substrate that the mushroom mycelium can rapidly grow on, ultimately producing a granular spawn that can evenly and easily inoculate the substrates used in Stage 3.

A variety of grains can be used in Stage 2. Rye berries, wheat berries, millet, and sorghum (milo) are common choices in commercial mushroom cultivation operations. Home cultivators also have success with spelt, popcorn, and whole birdseed. All of these grains are preferred due to their low levels of nitrogen and ease of preparation. Many other grains are too high in nitrogen, which can lead to overheating during mycelial growth or high contamination rates. Milo is preferred by some growers as it hosts over 30 types of vitamins and minerals as well as a small size, which provides for more points of inoculation in Stage 3.



Preparation of Grains

To produce the highest quality spawn, grains must be properly prepared prior to sterilization. Regardless of the grain being used, these are some guiding principles to keep in mind during your grain prep:

- **The grains should not be too hard.** When you bite into a grain it should be a little bit undercooked (*al dente*) for normal human consumption. There should be no hard center in the grain. In this state, the grain is fully saturated and supple enough for the mycelium to penetrate and digest it.
- **The grains should not be too soft.** There should be a minimum of sprouted or burst kernels after sterilizing. Overcooked, burst, and/or overly wet grains make grains more prone to contamination due to their protective outer layer being broken.
- **The grains should be easy to break up.** Dirty or overcooked grains can stick together, making it difficult for the mycelium to grow and/or later be broken up during Stage 3 spawning. Pre-rinsing grains and adding gypsum helps to reduce this stickiness.

The following basic recipe for grain prep helps address these three concerns.

1. Measure out 10–11 cups of dry grains into a large pot.
2. Fill the pot with water and stir the grains to suspend any dirt and debris that is present on the grains.
3. Pour off this dirty water and continue rinsing the grains until the water runs clear.

Grains can be fermented following the practices outlined for bulk substrates earlier and used as a substrate for Oyster (Pleurotus) species. However, as these grains are very wet, mushy, sticky, and acidic they are not a viable substrate for most other species.

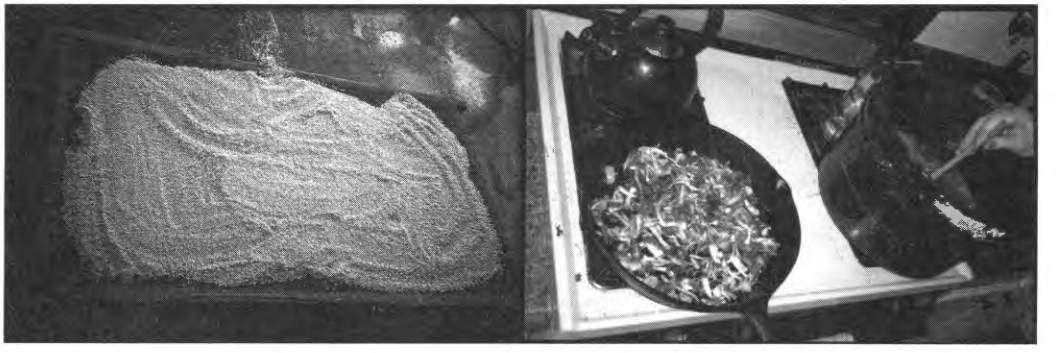
4. Cover the grains with high quality water.
5. Cover the pot and let it sit for 12–24 hours. Some cultivators soak their grains in 50% strength coffee to add additional nitrogen.
6. Place the pot on the stove and bring the grains to a boil for 5–10 minutes or until they are cooked to the right consistency.
7. Drain the grains through a colander. This nutrient-rich water can be saved and used for incorporating into agar and liquid media recipes.
8. Toss the hot grains around until they have cooled and the excess moisture has steamed off of them. If you are cooking a large amount of grains, spread them on your substrate prep screen (described in Stage 3) to speed cooling.
9. Add 1 tablespoon of gypsum evenly throughout the grains. Gypsum provides mineral supplementation while also helping to reduce the stickiness of the grains. Some cultivators add 1 teaspoon of hydrated lime to provide magnesium to the mycelium.
10. Fill each jar one-half to two-thirds full with the grains. A 16-ounce (475 mL) measuring cup and canning jar funnel significantly help to facilitate this process.
11. Seal each jar with an airport lid and cover the lid with an aluminum foil cap.
12. Pressure cook the jars for 60–75 minutes at 15 psi. Grains can also be tyndallized in the absence of a pressure cooker.
13. Turn off the stove and let the PC cool overnight.
14. Open the PC and remove the jars. Inspect each jar for cracks and/or an excessive number of burst kernels. Discard cracked jars.

Notes on Grain Prep

Soaking grains for 12–24 hours helps to germinate the dormant endospores of bacteria inside grains, making the endospores more susceptible to the heat of the pressure cooker. The amount of water used to soak and cook the grains should be the minimum necessary for achieving properly cooked grains. If too much water is used while boiling, beneficial nutrients will leach out of the grains and be lost. Trial and error will help determine the proper amount of water needed for your grains. Fuel costs can be saved in this process if the grains are cooked to their proper state using a solar collector/pasteurizer. Smaller grains, such as millet, do not need to be cooked as soaking provides adequate hydration. These uncooked grains will be very wet and sticky on the outside and need to be dried off on a clean towel prior to sterilizing.

Brown rice, used for many commercial medicinal products, often turns out very sticky and needs extra attention. After soaking and cooking to the al dente state, spread the rice onto a clean towel and stir it occasionally with a spoon as it cools. Then load the rice into jars as gently and loosely as possible. After pressure cooking, lay the jars on their side to cool, occasionally turning and shaking the jars to minimize clumping in the rice.

A small amount (5–10% by volume) of the substrate from Stage 3 can be added to grain jars prior to sterilization to help initiate the enzymatic expression that the mushroom will ultimately require to consume the Stage 3 substrate. For wood-lovers, I tend to add 10% of properly hydrated sawdust to grains before sterilizing.



(Left) Grains can be quickly cooled and drained on a mixing screen.

(Right) When cooking grains for mushrooms, cook some mushrooms for yourself. And if you have one, drink a homebrew, too.

Inoculating Grains With Myceliated Agar

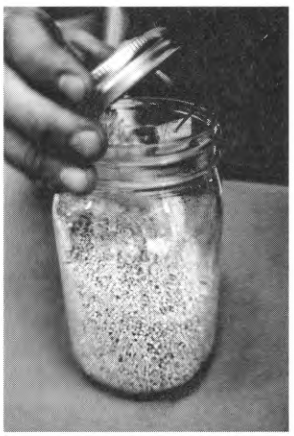
Once your grains are sterilized and cooled, they can be inoculated. Traditionally, myceliated agar has been the main inoculum for grains where, in a similar manner to a Plate-to-Plate Transfer, a wedge of myceliated agar is moved to a sterilized jar of grains.

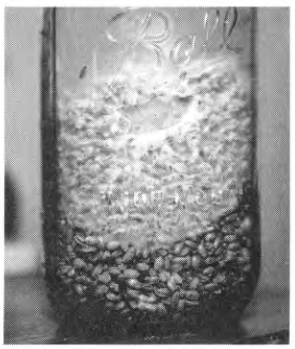
Materials

- Cooked, sterilized, and cooled jar of grains
- Myceliated petri dish
- Scalpel or spatula
- Tool sterilization materials

Method

1. Prepare your transfer space for aseptic work.
2. Shake the jar to loosen the grains. Shake the grains so that they are sloping in the jar.
3. Unwrap the myceliated plate and loosen (but don't open) the lid on the grain jar.
4. Sterilize your scalpel or spatula with a heat source and allow it to cool.
5. Clamshell the petri dish open, then cut out and extract a wedge of agar with your tool. Ensure that the piece has some amount of leading edge mycelium.
6. Close the petri dish lid.
7. Open the loosened grain jar lid as minimally as possible to drop the agar wedge in to the jar on to the lower end of the sloping grains. Do not place your hand over the opening of the jar. Try to not touch the tool to the jar.
8. Close the jar lid and tighten it down.
9. Gently shake the grains over the agar wedge so that they cover the mycelium. This move helps keep the mycelium from drying out as it recovers from the shock of being transferred. It also provides the fungus with easy access to the grains.
10. Wrap the plate. Label the jar with species/strain and date and set it to incubate.

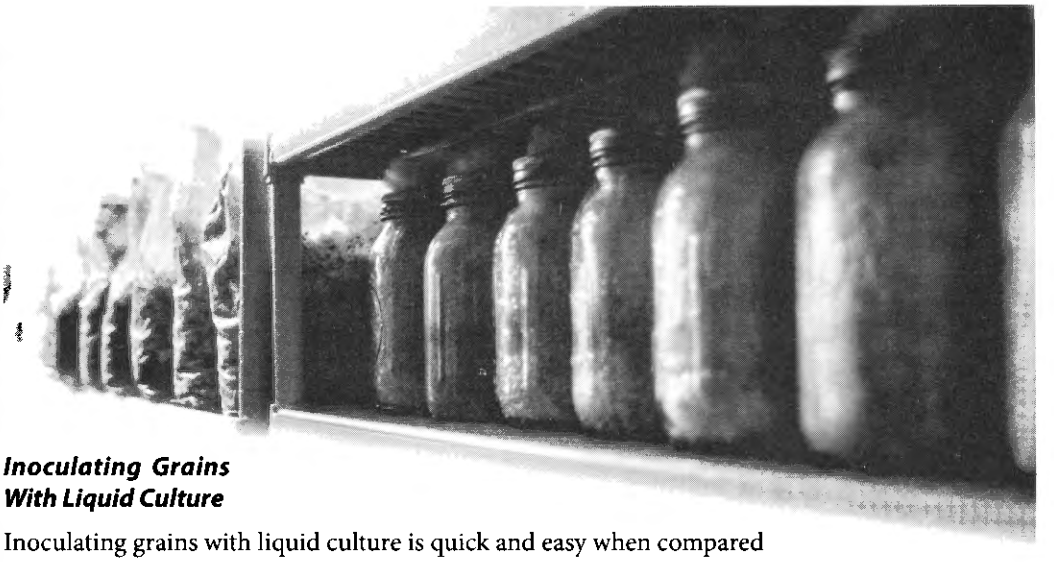




If inoculating multiple jars at once, loosen all the jar lids in advance. The mycelium on the agar should be cut into even sections that each contain some amount of leading edge mycelium. Going down the line of jars, quickly inoculate each jar with a piece of myceliated agar. If the transfer tool touches anything between transfers, sterilize it again. Under ideal conditions, one standard plate can inoculate up to 10 quart-sized jars of grain. However, the high inoculation rate obtained from spreading one plate to only 3–6 jars will increase myceliation while also reducing the time frame that competitors have to invade.

Measuring Moisture Content

While testing grains by biting into them is a great means for checking the state of a cooked grain, the exact water content can be measured for more precision. Properly cooked grains should have a moisture content of 55-65%. To test this, weigh out 100 grams of prepared grains and then place them on a baking tray in an oven heated to 350°F (177°C). Bake the grains for 20 minutes or until they are completely dry. Weigh the dried grains. The difference in weight will correspond to the moisture content that the cooked grains held. For example, if the grains come out to be 35 grams, then 65 grams of water had been lost in the oven. This means that the method used for preparing the grains yielded a 65% moisture content.



Inoculating Grains With Liquid Culture

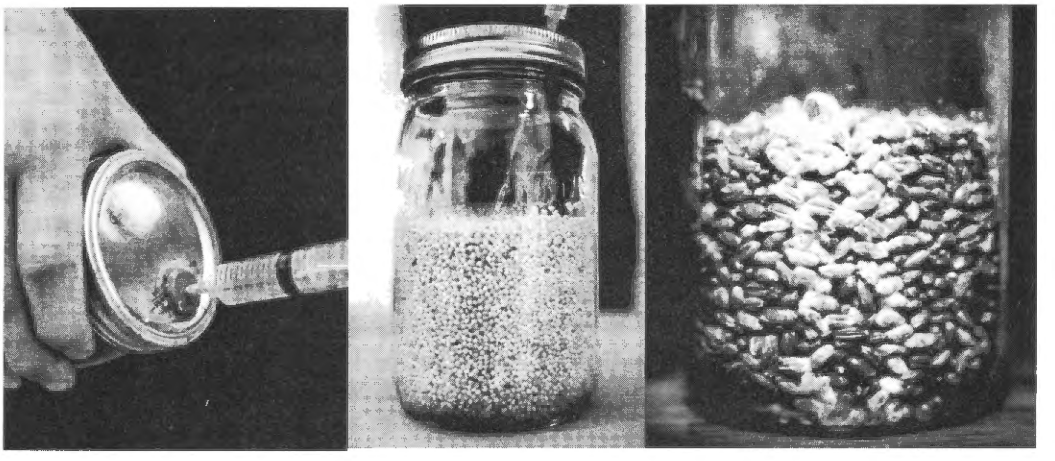
Inoculating grains with liquid culture is quick and easy when compared to the stress and sterility required for agar inoculations. This technique is similar to that used for Liquid-to-Liquid Transfers.

Materials

- 1 myceliated LC jar
- 1 sterilized grain jar with airport lid
- 1 sterile 60 mL syringe with a 16-gauge Luer-Lok needle
- Alcohol and sanitizing materials

Method

1. Clean the silicone ports on both jars with an alcohol wipe or alcohol-sprayed cotton ball then spray both ports with alcohol.
2. Insert the syringe needle into the LC jar and extract roughly 2–10 milliliters of the liquid culture per quart jar of grains. Be sure you are drawing out mycelium and not just sugar water.
3. Withdraw the needle and insert it into the grain jar. Swirling the needle around gently, spray the mycelium across the grains.
4. Repeat with each jar. If the transfers are taking a long time, spray the top of the uninoculated grain jars with alcohol again before inoculating. I prefer to use a large syringe for this process to reduce the number of times I enter the liquid culture jar.
5. Label each inoculated grain jar and set them to incubate.



Scaling Up

The above processes can easily be expanded to larger quantities of grains and larger vessels. Grain prep times may need to be adjusted to properly hydrate larger volumes of grains. Pressure cooking times should also be increased accordingly to ensure complete heating throughout the substrate. Half-gallon jars should be cooked for 90 minutes and one-gallon jars and filter patch bags are cooked for 2 hours.

A larger amount of inoculum will also be necessary for these larger quantities of grains. One gallon of grains can be (heavily) inoculated with 120 milliliters of liquid culture inoculum or several large pieces of myceliated agar.

Break, Shake, and Incubate

After inoculation, grain jars should be left alone for several days. Soon, the introduced mycelium will begin visibly growing on and through the grains. Roughly 3–8 days later, when 25–35% of the grains are myceliated, the jars should then be shaken for 20–30 seconds to break up the developing mycelial network and distribute the myceliated kernels throughout the jar. This helps increase myceliation rates. While I prefer to only shake once, some growers shake their jars a second time at around 70% myceliation. Shaking at 90%+ myceliation often stunts the mycelium's growth, negatively impacting the success of later expansions.

Grain-to-Grain Transfers

Grain spawn can be expanded to more sterilized grains before being moved on to Stage 3. Taking this extra step to expand your mycelial mileage helps reduce the need for constant agar work. However, compared to the open-air ease of inoculating grain with liquid culture, I do not do many Grain-to-Grain Transfers as they require an aseptic transfer space. But your needs may vary.

Materials

- 1 jar of healthy myceliated grain spawn that is not overgrown
- Multiple jars of cooked, sterilized, and cooled grain spawn

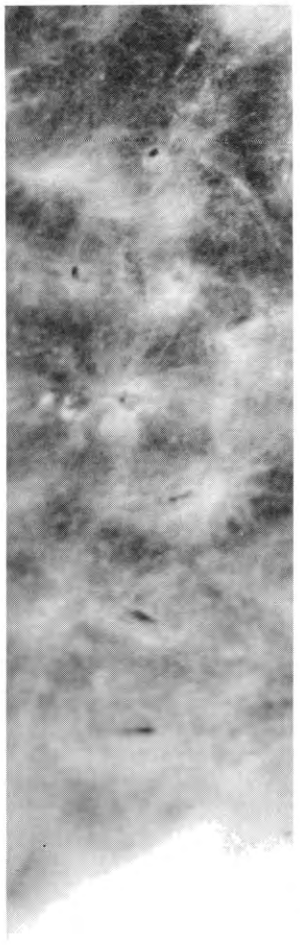
Method

1. Under aseptic conditions in your transfer space, loosen (but don't fully open) all jar lids and arrange them for easy access during transfer.
2. Open the myceliated jar on its side to reduce the number of ambient competitors entering the jar.

(Above, top) A bulk bag of grain spawn being myceliated by an agar wedge.

(Above) Elm Oyster millet grain spawn. This bag was inoculated two weeks earlier with 120 milliliters of liquid culture.

(Left) Resihi grain spawn before and after shaking. The spawn on the left is at an optimal state for transferring to a fruiting substrate. The grains are fully myceliated but the individual kernals are more or less visible and the mycelial mat hasn't turned into a hard mass.



3. Quickly and carefully open the lid of the first jar just enough to introduce 10–20% of the myceliated jar's grains. Rotating the jar as you pour helps in this process.
4. Close the lid on the freshly inoculated jar.
5. Repeat for each remaining new jar.
6. Tighten all lids. Label with date and species and set the jars to incubate.

Grain-to-Grain Transfers may be done twice (creating three generations) for most strains. Pushing for a fourth grain generation is not recommended as the mycelium will likely lose vigor after consuming so much of the same substance. Most growers prefer to only expand once (Gen. 2).

Liquid Grain Spawn to Grains

Some cultivators use an autoclavable Erbach blender to pulp grain spawn with water, creating a form of liquid inoculum. Alternately, many standard blender bottoms fit on a canning jar and can be autoclaved to achieve the same effect. This liquefied grain spawn can then be used to inoculate more grains or the substrates used in Stage 3. Compared to the ease of the liquid inoculum produced in Stage 1, this approach is less appealing to me personally. But some cultivators stand by this approach due to the high density of mycelium and nutrient load it affords.

If left in a container for an extended period, mushroom mycelium often produces a bath of digestive enzymes, antibiotics, and waste products.

When is Grain Spawn Ready for Stage 3?

Learning to spot when grains are ready to move onto another substrate is critical for successful cultivation. If grains are overgrown, the mycelium may become stunted in its growth and/or begin to initiate fruiting. Overgrown grains also tend to form a very dense mycelial mat, making it difficult, if not impossible, to break them up by shaking. Myceliated grains should be moved to their next substrate as soon as every kernel is covered in a visible coat of mycelium. After shaking the grains at around 30% myceliation, watch the mycelium distribute throughout the jar. Once all the visible grains are myceliated and no bare grain surface is visible, it can be assumed that the grain spawn is ready to move.

Stage 3: Preparing and Inoculating Fruiting Substrates

Once your grains are ready, they are moved to the next and (for indoor cultivation) final substrate. Depending on the species being cultivated, this final substrate will fall into two broad categories:

- **Wood:** The species that prefer wood are generally early-stage decomposers. These species tend to prefer fresh, wood-based substrates, typically in the form of sawdust, wood chips, or logs of hardwood trees. Some wood-loving species can grow on coniferous wood while others (e.g. some Oyster species) can fruit off of a variety of organic substrates, such as straw, hair, or corncobs. The wood-lovers comprise the bulk of the commonly cultivated species.
- **(Faux) Compost / non-wood:** A smaller number of commonly cultivated mushrooms are later-stage decomposers, preferring partially digested substrates. Most of these species tend to produce the highest yield on true compost, though many will fruit rather well off of a blend of fresh substrates and/or manure (faux compost).

These two groups contain some overlapping species. There are also outlier species that fruit off of unique substrates (e.g. Cordyceps spp. *and* Tremella fuciformis*).*

The Wood-Lovers

The grain spawn of wood-loving species is typically expanded in two ways depending on whether the cultivator wants to install outdoor mushroom patches or fruit mushrooms indoors.

- **Plain sawdust spawn for outdoor installations:** To grow sawdust spawn for outdoor mushroom installations, myceliated grains are expanded to pasteurized plain sawdust in open air. Plain pasteurized sawdust kits are an easy, effective, and cheap way to grow large quantities of mycelium for outdoor installations in gardens, for remediation experiments, or to plug logs. Indoor fruiting on plain sawdust generally results in relatively low yields due to the low amount of available nitrogen in the sawdust. If you wish to fruit these kits indoors, higher amounts of myceliated grains can be used to potentially produce yields comparable to nitrogen-supplemented sawdust kits. Regardless of the inoculation rate, some wood-loving species do not myceliate well with this method.
- **Nutrified sawdust kits for indoor fruiting:** For fruiting mushrooms indoors, many growers spawn myceliated grain to sawdust that has been supplemented with a nitrogen source to increase myceliation rates and improve yields. However, as the addition of this nitrogen source makes these kits very prone to contamination, they must be sterilized and inoculated under aseptic conditions.

Notes on Wood Quality

All wood-based substrates should, as closely as possible, meet the following requirements:

- **Correct wood**: Some species of mushrooms will only grow on the wood of specific types of trees. Other species/strains are more tolerant of a range of wood species.
- **Quality wood:** Wood should generally not be from a tree that is diseased or harboring another fungus. However, if you are experimenting with a species that is found fruiting on highly degraded wood, you may try to mimic this ecological niche by using wood that has been partially digested by another fungus. If you use such wood, it would be best to compare inoculations of sterilized and non-sterilized forms of this wood. Further, wood should be harvested in a way that is sustainable and based on a sound understanding of forest ecology and maintenance.
- **Sugary wood:** Ideally, the wood was harvested in late winter/early spring, just before the tree buds out. At this time, sap is running in the cambium layer of the wood and the bark is tighter, decreasing the risk of bark slippage if the wood is used for log culture. This increased sugar and nutrient supply makes the wood as rich as possible for healthy and vigorous myceliation and higher yields. Sawdust

Fruitwoods are generally not preferred due to their density, but they can can work, especially if mixed with a softer hardwood.

is often a mix of all parts of the tree, so this timing of harvest issue isn't quite as vital for sawdust work where supplements can be added. Trees that were grown in the open and with plenty of access to sunlight tend to have a thicker, sugar-rich cambium layer, making these trees preferable to those harvested from the inner parts of a forest or woodlot.

- **Fresh wood:** The wood should be as fresh as possible. Uninoculated wood can become contaminated with ambient fungal spores. Using your wood soon after harvest is preferred for this reason. During storage, woodchips or sawdust piles should be laid on a tarp in a shallow layer to discourage spontaneous composting or internal mold growth.

On Sourcing Hardwood

One of the greatest challenges to the small-scale cultivator is finding a consistent source of high quality hardwood. While some landscaping supply companies sell alder or other hardwood sawdust, most do not. There are several main routes to overcoming this hurdle:

- Sawdust can be sourced from lumber mills, furniture shops, wood turners, broomstick factories, and other wood processing industries. Call around.
- For smaller operations, hardwood pellets used for wood stoves work well. These compressed pellets of sawdust typically contain no chemical binders and readily hydrate. If you choose to regularly use this substrate, determine the exact ratio of pellets to water needed to obtain the proper moisture level.
- Contact local utility companies and municipalities that regularly prune trees. They might be willing to deliver chips to you, or at least tell you where their dump sites are located.
- Form a relationship with an arborist who is willing to contact you when they harvest wood that meets your criteria. Some tree service companies also leave woodchip piles on their property that can be harvested for free.
- Rent or buy a wood chipper and make your own chips. Scrap hardwood can be sourced from lumber mills.
- Purchase bags of hardwood chips used for smoking meat.
- Some landscapers sell "ramial" wood chips, which are ideal for mushroom cultivation.

On Sourcing and Using Soft Wood

Most of the commonly cultivated species do not grow well on soft, coniferous woods. This is due to the low nitrogen content of these woods and/or the presence of anti-fungal compounds, such as volatile organics. Some cultivators have had mixed results fermenting coniferous woodchips using the technique described earlier for pasteurizing substrates. Two rounds of fermenting are recommended here to best leach the prohibitive compounds.

In SE Asia, pinewood is fermented in the sun for a month to make it viable as a substrate. The sawdust is piled 1.5 feet (0.5 m) high, hydrated to a 60% moisture content, covered with a black tarp, and turned once a week for 4 weeks until it is softened, yet not rancid smelling. The wood is then supplemented as normal and heat-treated. Some mushroom species can grow directly on certain softwoods. For example Shiitake, Conifer Tuft, Enoki, and Comb Tooth can be grown on Douglas-fir wood if adequate nitrogen supplementation is provided. Three woods that are not advised are cedar, cypress, and redwood (all members of the Cupressaceae) as they contain anti-fungal compounds. That said, some mushroom strains have been known to adapt to uncommon wood substrates. If you encounter a desirable mushroom growing on a wood species outside that mushroom's typical preference, clone it!

Plain Pasteurized Sawdust Kits

Hydrating Plain Sawdust

Properly hydrated sawdust is the key to ensuring healthy and vigorous myceliation of wood-based substrates. If sawdust is too dry, the mycelium won't have enough water to grow. If the sawdust is too wet, it can become anaerobic, causing the mushroom to suffocate or not enter the wetter, lower parts of the container.

Water absorbs slowly into dry sawdust, requiring one to tend to the hydration process over a period of 1–2 hours. It is best to add small amounts of water at a time, mix the sawdust, return 10–20 minutes later to mix the sawdust again and check the moisture content. Avoid over-hydrating the sawdust. It is better to err on the side of making sawdust too dry rather than too wet.

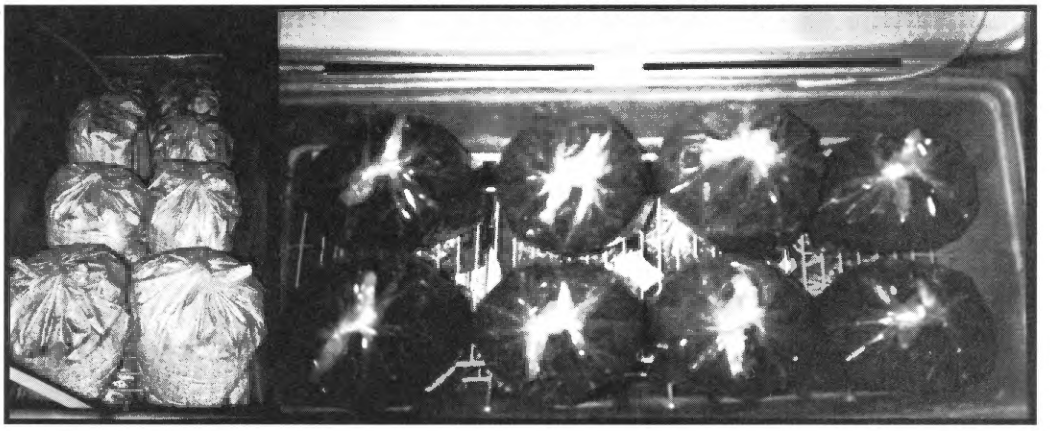
When the sawdust is at field capacity it should feel moist and yet should not leave water on your hand after holding. It should be able to hold its form when squeezed, but when squeezed very hard should only produce a small number of water drops. It should feel as moist as fresh potting soil or a wrung out sponge, be relatively fluffy, and never leave standing water in a container. Technically, the moisture level should be around 60–65%, but I never measure this. Experienced cultivators always ensure the proper hydration of any substrate using a feel test.

Small amounts of sawdust can be hydrated in a 5-gallon bucket. Larger quantities can be manually hydrated and turned on a wire screen unit. Substrate tumblers help hydrate larger quantities. I do not soak or ferment sawdust as this leaches nutrients while making the sawdust too wet to work with directly.

If you plan to harvest your own wood, be sure to take a course on proper chainsaw operation. The "Game of Logging" is one of the better chainsaw training programs in the U.S.[15]

Pasteurizing Sawdust

Once the sawdust is properly hydrated, it can be loaded into any heat tolerant vessel and pasteurized using one of the methods described in the section *Pasteurizing Pre-Hydrated Substrates*. Jars work well for pasteurized sawdust as the spawn will later be removed from the jar for outdoor installation. Polyethylene bags are cheap and can withstand pasteurization temperatures but require the addition of a makeshift air filter (see below). If using bags, an easy way to close them for pasteurizing is to expel the air from the bag (without compressing the sawdust very much), roll down the top of the bag, and tie the rolled top with its two ends. I generally load around 1–1.5 gallons (4–6 L) of hydrated sawdust into each bag prior to pasteurizing.



Inoculating Pasteurized Sawdust

Pasteurized sawdust can be inoculated with myceliated grains outside of the transfer space. This is because the sawdust is not sterile and thus not a blank slate. Plain sawdust also does not provide the readily available nitrogen that competitors need as the nitrogen is locked up in the lignin of the wood and the grain spawn is protected by a mycelial coat. Still, transfers should be done quickly in an environment that is as clean as possible to avoid contamination, which can occur with this technique.

Materials

- 1.5-inch (4 cm) piece of 2-inch (5 cm) diameter PVC collar, or a paper towel tube
- 1 myceliated grain jar
- Jars or bags of pasteurized sawdust
- Rubber bands
- Synthetic fiberfil

Method

1. Shake the grain spawn to break up the grains for transfer.
2. Open the sawdust bag and fold over its top as you set up.
3. Open the grain jar and quickly inoculate the sawdust. I use around 0.5–1 cup (100–250 mL) of myceliated grains for every gallon (4 L) of pasteurized sawdust.
4. Close the grain jar.
5. Close the sawdust bag and shake the contents to evenly distribute the grains throughout the bag.
6. Insert the top of the bag through the collar. Fold the bag opening over and fill the hole with synthetic fiberfil. Use a rubber band to secure this filter.
7. If you are inoculating multiple bags, open them all up first and quickly inoculate them, one after the other.
8. Label the bag and set to incubate.

Incubating Sawdust Kits

Inoculated sawdust kits can be stacked around 5–8 bags high in the incubation space to myceliate. Some species will form thick mycelial mats around the sawdust block while others do not. These kits take from 3 weeks to 3 months to fully myceliate, depending on the species. I do not shake the sawdust while it is myceliating as most species do not recover from this disturbance.

Dealing With Contaminants on Pasteurized Sawdust

Without an easily available nitrogen source, contaminants do not gain a foothold on pasteurized sawdust as readily as in nutrified kits. When molds do appear, try to simply remove these contaminants by hand. Bacterial competitors may proliferate if the sawdust is too wet. In either case, if the bag is overrun by competitors you can try to rescue the mycelium by moving a healthy portion to a small amount of woodchips or another naturalized substrate.

No-Tech Kits

Some species will grow quite well on hydrated sawdust that has not been pasteurized. King Stropharia, Turkey Tail, *Psilocybe* species, and the Oyster complex are aggressive and defensive enough that they can quite easily defend against any competitor that develops. Apart from saving on the cost and labor of pasteurization, another advantage to this method is that nearly any clean container can be used in place of jars or plastic bags.

When using non-pasteurized sawdust I tend to inoculate with around 1 cup per gallon (0.25 L per 4 L) of myceliated sawdust, shake, and set to incubate. The mycelium will soon begin to grow as normal but after 4–7 days its vigor tends to slow down as it encounters proliferating bacteria. A microbial war ensues, and within a couple days the leading edge of the advancing mycelium will begin to produce a large amount of yellowish antibiotic metabolites as it seeks to determine how best to fight off the competition. Usually the mycelium "figures it out" within a few days and continues to grow as before, this time unimpeded. So cool.

Nutrified Sawdust Kits

Sawdust kits designed for indoor fruiting contain supplementation and are typically pressure cooked in polypropylene filter patch bags, cooled, and then inoculated under aseptic conditions. Many farms prefer using jars as fruiting containers for this substrate, typically for King Oyster, Reishi, and Enoki, as well as other species.

Mixing and Hydrating Nutrified Sawdust

Below is a standard formula (by volume) for nutrified sawdust spawn. To elaborate on this basic recipe, refer to the section *Substrate Formulation*.

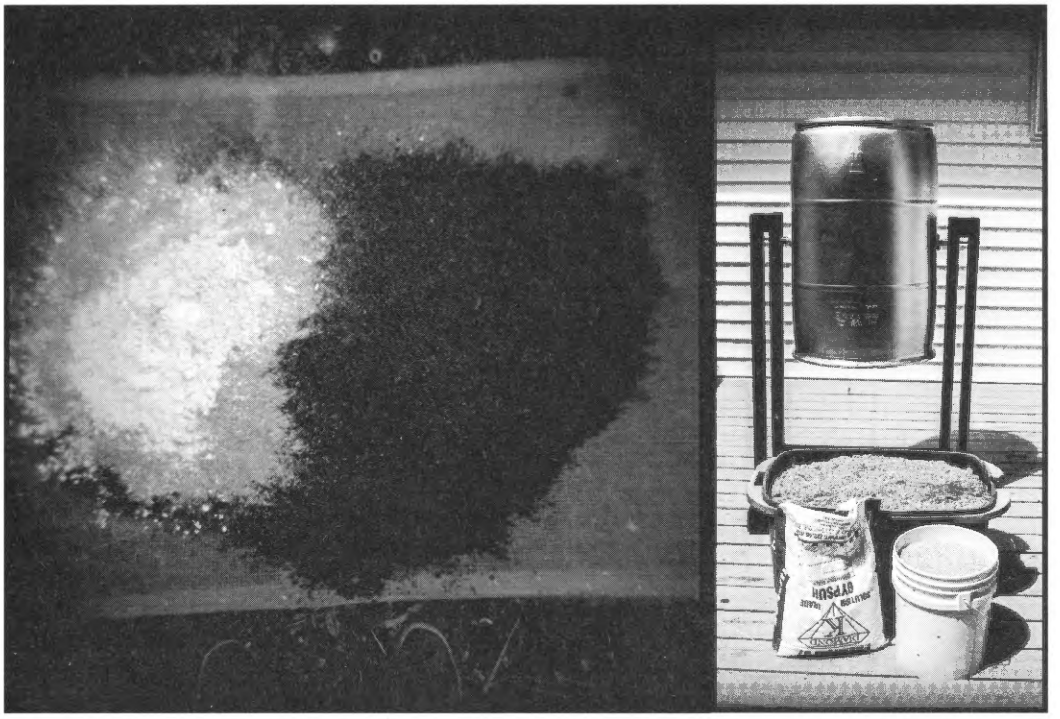
- 10 parts hardwood sawdust *OR* 5 parts sawdust and 5 parts wood chips
- 2 parts oat, rice, or wheat bran
- 1 part gypsum

Thoroughly mix the dry ingredients on a wire screen or in a substrate tumbler, then slowly hydrate the mixture to bring it up to field capacity. This watering process is essentially the same as for pasteurized sawdust. One notable difference is that the bran and gypsum quickly retain more water than plain sawdust, decreasing the time needed to wait for adequate hydration. Properly hydrated nutrified sawdust should feel light, fluffy, moist, but not too wet. When it is firmly squeezed it should produce a short stream of water, not just a couple drops. This extra water holding capacity of nutrified sawdust also contributes to the increased yield obtained from this substrate.

Once the nutrified sawdust is properly hydrated it is then loaded into jars or filter patch bags. Filling a large number of bags can be facilitated by a using a standardized scoop or with a substrate tumbler with a lid modified for loading. Five to six pounds (2.25–2.75 kg) of substrate is a standard weight per bag. Weighing each bag after loading ensures consistency and helps to track biological efficiency. Once the bag is filled, wipe down the upper, inner portion of the bag if it is dirty. This reduces the risk of contamination during inoculation.

On Nutrified Sawdust Ingredients

Wheat, oat, and rice bran are commonly used nitrogen sources. If you have the means, adding 25–50% hardwood chips to the substrate mix can extend the life of the kit as well as increase yields. Woodchips should be soaked overnight prior to mixing, so as to hydrate them. Gypsum is a commonly added mineral supplement. Adding a substance with a high capacity for water retention can also help increase yields. One study found that replacing 20% of nutrified sawdust with hydrated biochar had no impact on yields.[16] The production of biochar is discussed in Chapter 9.

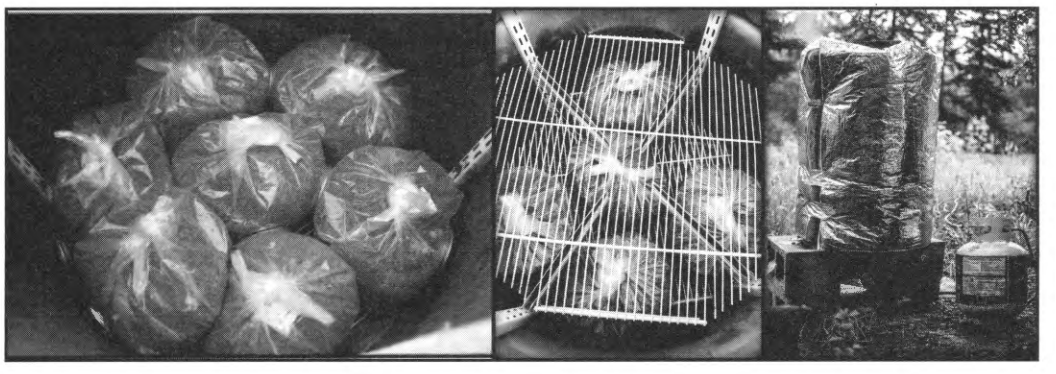


Sterilizing Nutrified Sawdust

Once kits are loaded, they are closed and sterilized using one of the methods described earlier. Similar to pasteurized bags, I prefer to expel the air from the bag, roll down the top and tie it off with the ends of the rolled top. Rolled as such, sterilized bags can be stored for extended periods of time and moved between workspaces with reduced concern of contamination.

The 3–8 bags that fit in a standard pressure cooker should be sterilized at 15 psi for 2–3 hours. A 55-gallon drum retrofitted with racks can hold 25–35 nutrified sawdust bags. With the drum lid in place, but not sealed, the bags are then steamed ("ultra-pasteurized") in the drum for 8-10 hours to sterilize them. This steam can be produced from 7 inches (18 cm) of water in the bottom of the drum, or it can be piped in from a pressure cooker or another metal drum. These kits can also be tyndallized for two hours at a time on three sequential days.

55-gallon drums can also be modified with pressure regulating systems and used like a large autoclave. These drums can only maintain a pressure of around 3 psi, which cuts cooking time down to six hours. A drum lid can also be rigged with a pressure gauge and petcock. This low-cost, low-pressure autoclave must be monitored as the drum could potentially blow up if left unattended!



Loading shelves with nutrified sawdust kits. Lid rings pad each bag to ensure good air flow. The sterilizing drum is insulated while cooking to reduce fuel inputs.

Inoculating and Incubating Nutrified Sawdust Kits:

Nutrified sawdust must be inoculated under aseptic conditions. As inoculating many tall bags in a small glove box can prove challenging, this is one process that greatly benefits from the use of a flow hood.

Materials

- Jar of myceliated grain spawn
- 5-pound (2.25 kg) bag of sterilized and cooled nutrified sawdust
- Wire, impulse sealer, or electric food preservation sealing preserving unit

Method

1. Shake the grain jar to break up the grains.
2. Under aseptic conditions, open the sawdust bag and grain jar.
3. Quickly pour approximately 1 tablespoon of myceliated grains into the sawdust bag without placing your hands over the opening of the bag. Rolling the jar while you pour helps the grains easily fall out of the jar.
4. If using a flow hood, fill the bag with a plenum of air.
5. Seal the bag. This can be done by simply rolling down the bag and tying it with a piece of stiff wire. For larger operations, bags can be quickly sealed using a heating element such as those in an impulse sealer or food preservation unit. Check for a proper seal by gently squeezing the bag and listening for a hiss. Reseal the bag or patch any holes with tape if needed.
6. Shake the bag to distribute the grains.
7. Label with date and species/strain and set to incubate.

With the additional nitrogen, around 1 tablespoon of grain spawn is all that is needed to inoculate these kits. In front of a large flow hood, an assembly line can be set up with multiple people to increase the efficiency of this repetitious process. Nutrified kits are incubated standing up and with a slight air gap between them to minimize overheating.

(Above) Closing bags with stiff wire is a good option when working in a glove box or other constricted space.

(Right) A flow hood and impulse sealer enable quicker work when doing a large number of bags.

Putting it All Together

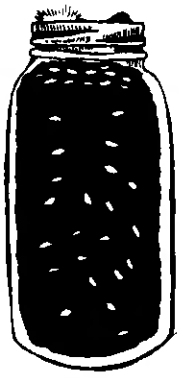
The following are two simple routes that I commonly take to combine the above concepts and skills and also avoid a lot of the labor involved in the cultivation process.

Cheap and Easy Bulk Spawn

Inoculate liquid media outside of a transfer space by taking a biopsy of a mushroom. Inoculate grains with the LC and spawn these grains to pasteurized sawdust. This is the simplest, cheapest means for producing a consistent supply of high quality and vigorous spawn for outdoor installations. If all materials are cooked, tyndallized, and pasteurized with solar heat, a pressure cooker and aseptic environment can be avoided.

All-in-One Fruiting Spawn

A filter patch bag can be modified to receive LC by applying a thick blob of RTV silicone. Once the silicone has cured, cover the blob with packaging tape to ensure that it does not fall off. Fill the bag with 5–6 pounds (2.25–2.75 kg) of nutrified sawdust and place 2 tablespoons of freshly cooked grains just below the LC injection site. Close the bag and pressure cook it for 2 hours at 15 psi. Once cooled, seal the bag in the transfer space and then inoculate with 30–180 milliliters of LC. Once the grains are myceliated the contents can be shaken and then set to incubate. This practice can also be applied to 0.5 gallon (2 L) mason jars, which do not necessitate aseptic closure after heat treatment and thus avoid the transfer space entirely. Fruiting from these All-in-One LC-inoculated, nutrified sawdust filled jars is arguably the easiest and most effective means for creating an abundance of high quality yields from some of the most popular cultivated mushroom species. I recommend this route to anyone who wishes to establish a low-input mushroom cultivation operation. Further, this practice can readily extend to species that are cultivated for their edible and/or medicinal sclerotia: *Polyporus umbellatus, Lignosus rhinoceros, Omphalia lapidenscens, Pleurotus tuber-regium, Wolfporia extensa,* and *Xylaria nigripes.*



(Left) These All-in-One jars are one of the most efficient and effective ways to grow edible and medicinal mushroom year-round with minimal cultivation infrastructure. After being filled with nutrified sawdust and grains, the jars can be sterilized en masse in a 55-gallon drum, cooled, then inoculated outside the lab with a liquid culture syringe.

(Below) Depending on the cultivator's goals, the various stages in the traditional cultivation methodology each have their place, but not all are necessary to produce edible mycelium and fruit bodies.

Plain Straw

A handful of mushroom species are commonly fruited from pasteurized, non-supplemented straw. These include the Oyster complex, Elm Oyster, Pioppino, Paddy Straw, and some Shiitake strains. Straw is an ideal substrate due to the physical structure of the straw shaft, which can both retain a high amount of water and yet be tightly packed into a container without impeding airflow or mycelial growth. The following concepts apply to other agricultural waste streams as well. If using alternative substrates, be sure to review the earlier section on substrate formulation.

Shredding Straw

Straw should be shredded into 1–3-inch (2.5–7.5 cm) pieces to provide the mycelium with a maximum surface area for myceliation. Cutting the straw any shorter risks the creation of dead-air zones inside the substrate where anaerobic decomposition (rotting) can occur. Straw is easily shredded with an electric, gas, or bike-powered yard debris shredder; with a lawn mower; or in a large plastic tote or trashcan with a weed whacker.

Pasteurizing and Inoculating

Straw needs to be pasteurized prior to inoculation. All of the methods listed in the section *Pasteurizing Non-Hydrated Substrates* work well for straw. Some farms will soak straw for 24 hours prior to pasteurizing to fully hydrate it. Other growers use sudsy castile soap water as a wetting agent to reduce this pre-hydration soak time to 2 hours. The soap does not need to be rinsed off prior to pasteurization. Many growers do not pre-soak their straw. After the straw has cooled from pasteurizing, it can be inoculated in two ways:

- **On a table:** A table or small children's swimming pool is washed with soap and water and then wiped with isopropyl alcohol. The straw is spread out and the grain spawn is mixed in as thoroughly and cleanly as possible (an alcohol-washed pitchfork can help with this). The inoculated straw is then tightly packed into a container.
- **In the container:** In a "lasagna-style" approach, straw is tightly packed into a container in 2–3-inch (5–7.5 cm) layers. In between each layer, grain spawn is lightly sprinkled across the straw surface. This layering process is repeated until the vessel is filled and then tightly packed and sealed.

Packing Straw

Any large air pockets in the inoculated straw container can enable fruit bodies to develop inside the vessel (an undesirable effect). To avoid this, straw must be tightly packed into its container. Five common containers are used for growing mushrooms on straw (or other waste streams):

- **No container:** In subtropical climates the fast-growing Paddy Straw mushroom is commonly inoculated directly into piles of wet straw that may or may not have been pasteurized. This is possible due to the rapid fruiting that occurs with this mushroom.
- **Laundry baskets/milk crates:** These large, hole-covered containers are ideal for growing mushrooms on straw. However, their extreme air exposure requires them to be covered in a loose fitting plastic bag during incubation.
- **Plastic buckets:** Reusable plastic buckets are a great way to cut costs and reduce waste. Fifteen to twenty 0.5-inch (1.25 cm) holes should be drilled around the bucket to enable the mushrooms to fruit. Buckets can be stacked on top of each other to form a fruiting tower. This is a great way to maximize the use of vertical space in a greenhouse or fruiting room.
- **Plastic bags:** Any clean bag will do, though thick polyethylene bags are preferred by many cultivators. Once the bag is packed, expel all air, and heat seal the bag or tie it off with a rubber band. Holes are then poked around the bag, spaced 2–3 inches (5–7.5 cm) apart in all directions. The best tool for this is an arrowhead with

Some compost-loving species (e.g. King Stropharia and Blewit) prefer fermented straw, likely due to the abundance of dead microbes.

a X-shape, which creates a crossed slit that allows the mushroom to easily fruit and expand out of the bag, while reducing moisture loss during incubation.

- **Plastic tubes:** Rolls of polyethylene plastic tubing can be cut to any length and packed with inoculated substrate. Black plastic reduces fruiting inside the tube but doesn't allow the cultivator to see what is going on inside the bag, hiding potential contaminants. Like bags, tubes are then tightly closed and holes are poked around its surface. Larger *strawsages* can have a metal ring incorporated into one end to make them easy to hang in the incubation and fruiting spaces.

Below is the standard protocol for inoculating a 3-foot (1 m) plastic tube. The same concepts described here apply to the other straw vessels as well, such as the buckets shown in the photos.

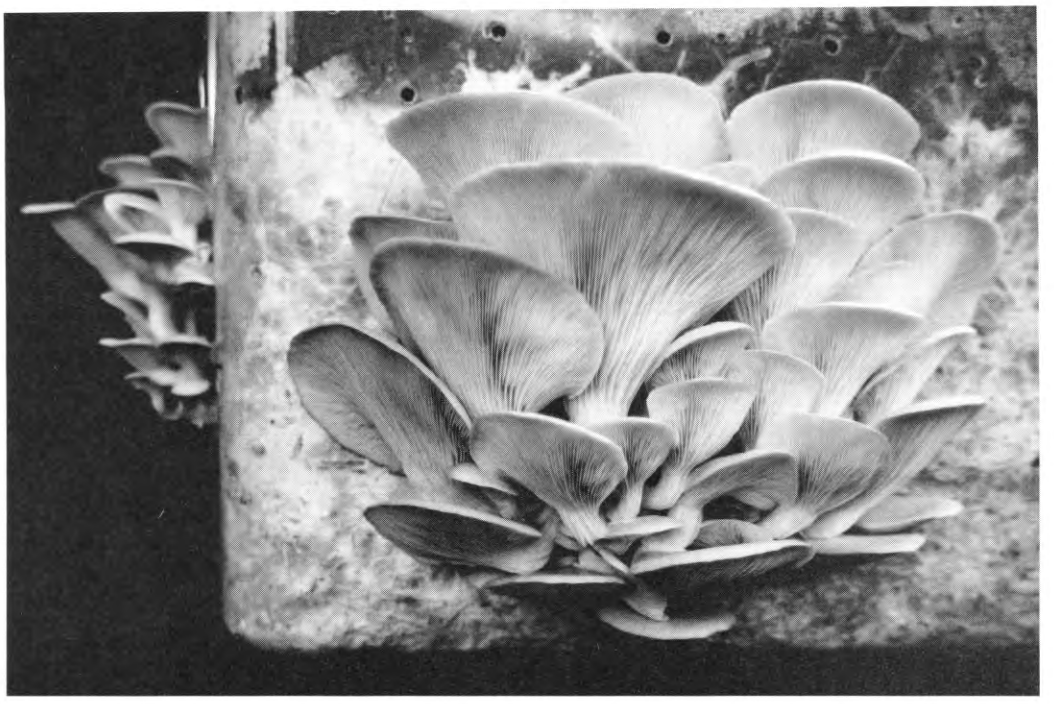
Materials

- Clean plastic bag/tubing
- Knife or arrowhead
- Oyster grain spawn
- Pasteurized and drained straw

Method

1. If using a plastic tube roll, cut off about 2 feet (0.6 m) more material than how long you want your finished tube to be and tie a knot on one end.
2. Add a layer of straw to a depth of a few inches. As you fill your log with straw, hold the straw in your hand, and gently sprinkle it down into the tubing, making sure it spreads evenly. You don't want dense clumps of straw, which can produce anaerobic pockets in the tube and/or air cavities between them, encouraging fruiting inside of the tube.
3. Sprinkle half a handful of grain spawn on top of the straw and then add a couple more handfuls of straw. Grain spawn is the preferred straw inoculum as it provides additional nutrients that sawdust or coffee spawn do not offer.
4. Repeat this process until the container is full. Occasionally stop and pack the contents down tightly. There's no need to stand on the contents or use equipment. Just push as hard as you can with your hands. For a big strawsage, you can lift and drop the tube, packing it under its own weight.
5. Continue to add spawn and straw until the tube is nearly filled then tie it off, maintaining compaction. Tie it as tightly as possible.
6. Using a clean arrowhead or sharp knife, cut 0.5-inch (1.2 cm) long, X-shaped slits around the entire surface of the tube. Space these slits about 2–3 inches (5–7.5 cm) apart in every direction to allow for adequate airflow.
7. Label the container with species and date then place the tube in the final fruiting space. Do not disturb the tube during incubation. Once pins begin to develop, turn up the humidity and airflow following the principles outlined for Stage 4 and the cultivation parameters for the given species.

After draining, straw is sprinkled into a container with grain spawn and packed down tightly.



After packing, straw kits and strawsages are set in the spawn run space to myceliate. Depending on the species and inoculation rate, the kit will start to fruit on its own in about one to four weeks. Move the bag to the fruiting room promptly when primordia appear. If the straw gets contaminated, place it outdoors where it may continue to fruit.

Scaling Up

Due to its ease and predictability, growing Oysters on straw is a common practice at most mushroom farms and, increasingly, vegetable and organic farms, often in 3–6-foot (1–2 m) columns. In my opinion, the most cost effective and efficient route for growing Oysters on straw is to ferment the straw and then spawn it in 5-ballon buckets with LC-inoculated grain spawn. One and a half gallons (5.5 L) of grain spawn can inoculate a bale of straw and fill about a dozen 5-gallon buckets. This is the minimal inoculation rate I recommend; doubling this amount will enhance yields. Once you get a rhythm with this practice, it is easy to produce year-round crops of this healthy and medicinal food for a very low cost.

Fruiting With the Seasons

The various species/strains in the Oyster complex vary widely in their fruiting temperature requirements. Some require very low temperatures to fruit, while others are sub-tropical and will die under such chilly conditions. If you plan to grow Oysters year-round, the best way to avoid the excessive electrical costs of temperature control is to grow with the seasons. The following is a generic calendar for fruiting some common species/strains in the temperate climate of the Pacific Northwest U.S. Adjust these time frames to match your local climate.

October–Jan.: Brown, Cold Temp. Blue
February–March: Brown, Warm Temp. Blue
March–April: Warm Temp. Blue, Elm (60–80°F [16–27°C]), Golden (65–85°F [18–29°C])
May–Sept.: Warm Temp. Blue, Elm, Golden, Pink (70–90°F [21–32°C]), Phoenix (70–90°F)

Supplementing Straw

The species cultivated on plain straw, along with the Button (*Agaricus bisporus*), Almond Portobello (*A. blazei*), and various *Psilocybe spp.*, generally produce greater yields on straw when a nitrogen supplement is added to the mix. This supplement can come in various forms of agricultural waste. The Oyster species and Shiitake prefer plant-based supplementation, while *Agaricus*, *Psilocybe*, and other later-stage decomposing species prefer manure-based supplementation. I refer to manure-supplemented straw as *faux compost* as it provides some of the benefits of hot compost (discussed soon), while reducing the need to create this more complex substrate. Manures that are commonly added to straw include:

- **Chicken manure:** High in nitrogen, chicken manure should only make up 1–5% of the substrate mass by volume.
- **Horse or cow manure:** Both of these manures can be used at a total rate of 30–40% by volume. If the manure is fresh, it needs to be leached of urine. This can be done by baking the manure in the sun or oven. Otherwise, old horse manure from the field is likely to have been leached by the sun and weather. These manures can be collected in bulk, dried, and then stored until later use. Manure slurry left over from biogas production (discussed in Chapter 9) has also been shown to be an effective supplement.[17] Likewise, leached cow manure can often be obtained from dairy farms.
- **Worm castings:** Readily made at home, the castings of red wiggler worms make a great supplement that closes waste loops. Castings should be added to straw at around 10% by volume. See Chapter 9 for more information on worms.

Planning and Scheduling

If you wish to cultivate large quantities of spawn or mushrooms, it is helpful to gain a thorough familiarity with the time requirements of each stage in the cultivation process. It is easy to get ambitious and spend a late night inoculating a bunch of grain jars only to find yourself overwhelmed 2 weeks later with mycelium and unprepared for the next stage in the process. Don't make this common mistake! Start small and slow and develop the habit of thinking ahead for all of your projects.

Agar growth: 5–21 days
Liquid culture growth: 10–30 days
Quart jar of grain growth: 7–14 days
5 lb. (2.25 kg) nutrified sawdust kit inoculation to fruiting: 3–12 weeks
Oyster straw kit inoculation to fruiting: 1–4 weeks

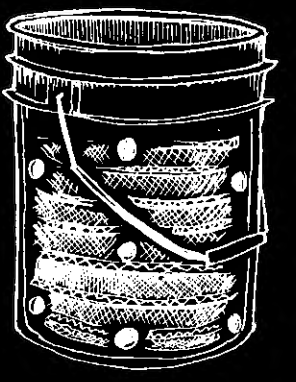
These approximate time frames can vary per the It Depends Clause. Once you gain a familiarity with your cultivation process and develop a rhythm, it is possible to develop a cultivation schedule that keeps your incubation and fruiting spaces full but not overcrowded. The best route to take is to first select your target species and gain familiarity with its growth habits and then develop a cultivation calendar for that species that matches your storage capacity, climate, substrate availability, and budget.

Other work scheduling factors to account for include preparing, soaking, and cooking substrates; sourcing, ordering, acquiring, and unloading supplies; building infrastructure; cleaning and maintaining workspaces; and outreach/marketing. All of these processes and energy commitments quickly add up to the fact that moderate scale mushroom cultivation can be a relatively time-intensive practice. However, working with others, using the best tools for the job, and acquiring proficiency and familiarity with techniques all increase efficiency. Stick with it. It does get easier.

Preparing and Using Straw Supplements

Manure supplements must be hydrated to field capacity and pasteurized prior to mixing with straw and inoculating. If using horse or cow manure, it is best to thoroughly dry and then break up the dung by hand or with a food processor prior to hydrating the material. All manures need to be pasteurized and not sterilized, so as to maintain their beneficial microflora. Pasteurization can be done using any of the methods listed in *Pasteurizing Pre-Hydrated Substrates*. Pasteurize the manure at the same time that you pasteurize the straw. Once both substrates are cooled, mix them at the recommended ratio, inoculate, and pack as for plain straw.

Coffee and Cardboard as Substrates: Food-Medicine for Low to No Dough



Many Oyster species have such potent digestive abilities that they can grow on a wide variety of agricultural and urban waste steams. For the urban grower, two of the most abundant and readily available substrates suitable for these species are coffee grounds and cardboard. Fresh coffee grounds are an ideal substrate as they come hydrated and essentially pre-pasteurized from the brewing process. They also maintain a nearly neutral pH while serving as a good nitrogen source. Fine espresso grounds can become anaerobic if packed too densely. Cardboard is a simple carbon source for the fungi that also increases aeration in coffee filled containers. Cardboard should be soaked for 30 minutes in water prior to spawning. Spawning to these free ingredients in reusable buckets or containers is one of the quickest and most inexpensive ways to grow mushrooms in an urban setting.

Coffee grounds have a tendency to contaminate if they are not inoculated soon after cooling. To address this issue, my friend James Weiser suggests using 1-inch (2.5 cm) layers of coffee grounds. To each of these layers, grain spawn or nutrified sawdust spawn is then evenly applied around the periphery of the container. A layer of hydrated cardboard is then laid down and the process repeated until the container is full. As the mycelium grows first around the edge of the container and then into its core, it will form a "stomach" around each layer of coffee grounds. If a mold arises on the grounds in the process, the mycelium will essentially grow around and over the competitor, trapping it and neutralizing its impact. Placing a brick on top of the final layer of cardboard provides a slight pressure on the substrate that helps increase myceliation rates.

The Compost-Lovers on Manure-Based Substrates

The same species that yield higher on manure-supplemented straw tend to also grow well on manure-dominated substrates, another faux compost. While grain spawn can be added directly to hydrated, pasteurized manure with varying degrees of success, supplementing manure with various additives is preferred to increase aeration and/or provide additional nutrients.

To increase aeration and the water holding capacity of manure-based substrates, the most commonly used additives are coconut coir and vermiculite. Coir is the shredded fiber of coconut husks. It holds many times its weight in water and takes years to decompose. It is pH neutral, inexpensive, and often available from natural mattress recyclers for free. Vermiculite is puffed mica that increases moisture-holding capacity and aeration. Another inexpensive additive is biochar, discussed in Chapter 9. Biochar can be added at 10–20% of the substrate by volume. All of these additives should be hydrated to field capacity on their own before being added to the other substrate ingredients. Many cultivators prefer to add some amount of straw to manure-based substrates.

Gypsum, coffee, oils, and other supplements are incorporated into a wide variety of substrate formulations to provide minerals, nitrogen, fats, or proteins to the fungi. To the side are several examples of manure-based substrate formulas. Refer to Appendix H for a list of substrate additives and to the *Substrate Formulation* section if you wish to elaborate on these recipes.

Example Manure-Based Substrate Formulas

60% Dried horse manure (by volume)
25% Coconut coir
10% Vermiculite
5% Coffee

12 parts Horse manure
6 parts Vermiculite
4 parts Dry whole bird seed
4 tablespoons Dry kelp meal
6 tablespoons Vegetable oil

1 part Dried horse manure
1 part Coconut coir
1 part Coffee
1 part Straw
1 part Coffee grounds
1 part Leached cow manure
0.75 parts Worm castings
0.25 parts Gypsum
Vegetable oil at 1 teaspoon per gallon of substrate

2 parts Leached cow manure
2 parts Coconut coir
2 parts Worm castings
2 parts Coffee grounds
0.5 parts Chicken manure
0.5 parts Hydrated lime

Inoculating and Incubating Manure-Based Substrates

Manure-based substrates are often spawned in shallow, horizontal trays as opposed to the bags and jars discussed thus far. Home cultivators often use plastic storage trays or baking dishes that have been washed with soap and water and then cleaned with alcohol. Larger operations use large trays that are often lined with clean plastic. These trays may be plastic, metal, or wood and 2–12 inches (5–30 cm) deep. A deeper tray can support more substrate and thus a greater yield for the same amount of surface area.

Trays are generally inoculated lasagna-style with thin layers of grain spawn between 0.5-inch (1.25 cm) layers of substrate. Alternately, grain spawn can be shaken into the substrate inside of a bag or large container (similar to how pasteurized sawdust is inoculated) before being poured into the tray. Do not fill the tray to the top; leave 1–2 inches (2.5–5 cm) of headspace. Cover the tray with aluminum foil and poke a tiny hole in the foil every 4–6 inches (10–15 cm) to allow for modest gas exchange. Label the tray and set it to incubate. Once the substrate is fully myceliated in 4–10 days, a casing layer is generally applied to facilitate the greatest fruiting.

C:N OF COMMON SUBSTRATES

Alfalfa meal – 15:1
Apple pomace – 13:1
Corrugated cardboard – 560:1
Carrots – 27:1
Castor pomace – 8:1
Cocoa shells – 22:1
Coffee grounds – 20:1
Comfrey – 10:1
Corn cobs – 60–100:1
Corn stalks – 60–75:1
Cow manure – 19:1
Crab/Lobster wastes – 4:1
Cranberry wastes – 30–60:1
Douglas-fir Bark – 491:1
Dried leaves – 70:1
Fish wastes – 2.5–5.5:1
Fresh grass clippings – 12–19:1
Fresh hay – 16:1
Fresh seaweed – 10–19:1
Fruit wastes – 15–30:1
Goat manure – 12:1
Grass clippings – 9–25:1
Hardwood bark – 225:1
Hardwood sawdust – 500:1
Horse manure – 20–25:1
Horse bedding – 30–60-:1
Human hair – 10:1
Legume hay – 15–19:1
Newsprint – 400–800:1
Oat straw – 50:1
Onion scraps – 15:1
Paper – 125–180:1
Paper fiber sludge – 250:1
Paper pulp – 90:1
Pig manure – 14:1
Potato tops – 28:1
Poultry manure (broiler) – 18–20:1
Poultry manure (laying) – 10:1
Rice hulls – 120:1
Seaweed – 5–27:1
Sewage sludge – 5–16:1
Sheep manure – 16:1
Shrimp wastes – 3.5:1
Shrub trimmings – 53:1
Softwood bark – 100–1000:1
Timothy hay – 60:1
Vegetable wastes (leafy) – 10:1
Vegetable wastes (starchy) – 15:1
Wheat straw – 150:1

HIGH NITROGEN ADDITIVES

Bat guano – 10% N
Blood meal – 13% N
Cottonseed meal – 6–7% N
Dried blood – 12% N
Fish meal – 11% N
Linseed meal – 5–6% N
Urea – 46% N

THE COMPOST-LOVERS ON COMPOST

The species that do well on faux compost tend to obtain the highest yield on fully composted materials produced in an aerobic (hot) compost pile. Aerobic compost is made by watering and piling a mixture of nitrogen- and carbon-rich organic wastes into a tall mound, which is then turned every couple of days for 1–4 weeks. During this time, oxygen-dependent (aerobic) and thermophilic bacteria, actinomycetes, and fungi will begin eating the organic matter and producing a lot of heat. Turning the pile is necessary to introduce fresh oxygen to these microbes and to maintain proper temperatures in the center of the pile. Hot composting is a relatively simple, semi labor intensive process that is dependent on four main factors:

- **C:N:** The ratio of the compost's carbon to nitrogen should be roughly 30–35:1 at the start of the pile. This ratio has been shown to be ideal as it provides enough nitrogen for the microbes to grow rapidly and efficiently compost the substrates, while not growing so fast that they overheat and kill themselves.
- **WATER:** The substrates must be thoroughly wetted when mixing the pile and re-hydrated at turning.
- **AIR:** The aerobic composting microbes need a lot of oxygen. Smaller operations turn their piles by hand to provide air. Larger operations use heavy machinery to turn the pile as well as pump fresh air up into the pile through ventilated holes in the ground. A "jungle-gym" of perforated PVC pipes can be used to make a forced air composting system.[18]
- **TEMPERATURE:** The internal temperature of the pile should plateau at 145–160°F (63–71°C). This temperature range supports the proper succession of microbes necessary to fully digest the pile's material into a viable mushroom substrate. Turning helps minimize overheating. A cold pile may be a sign of nitrogen deficiency. Extra nitrogen can easily be added in the form of urea (urine) or the cooled water left over after pasteurizing straw in *hot* water.

Calculating C:N

The C:N of a pile is calculated based on the combined C:N ratios of the ingredients used. Piles are often comprised of an abundant carbon source (the browns) and a smaller amount of a nitrogen source (the greens). To calculate C:N for a proper pile use the following formula:

1. Multiply the weight of each ingredient by its carbon percentage (150:1 = 150%).
2. Add these C percentages.
3. Multiple the weight of each ingredient by its nitrogen percentage.
4. Add these N percentages.
5. Divide the C percentage by the N percentage.

EXAMPLE

50 pounds (22.5 kg) wheat straw x 150% = 75 lbs. C
20 pounds (9 kg) poultry manure x 10% = + 2 lbs. C
77 lbs. of C.

50 (22.5 kg) pounds wheat straw x 1% = 0.5 lbs N
20 (9 kg) pounds poultry manure x 1% = 0.2 lbs N
12 (5.5 kg) pounds blood meal x 13% = + 1.56 lbs. N
2.26 lbs. N
77/2.26 = 34.01 = 34:1 C:N

On Compost Recipes

A wide variety of compost recipes have been developed over the years; some examples are listed to the side. Regardless of the available substrates, it is better to err on the side of adding too much carbon than nitrogen as you can always add more nitrogen later in the form of urine or other liquids. Many commercial *Agaricus* farms use wheat straw and chicken manure as the main ingredients in their compost. Most farms also add gypsum to their compost at a rate of 2% by dry weight. See Chapter 9 for information on biodynamic compost preparation.

Example Compost Recipes

5 bales Wheat straw
1,000 pounds Horse manure
30 pounds Gypsum
2 pounds Compost activator
70 pounds Chicken manure
4 pounds Blood meal

90.6% Rice straw
3.6% Fowl manure
2.4% Rice bran
1.9% Slaked lime
1.2% Superphosphate
0.3% Urea

75% Sugar cane bagasse
13% Cottonseed hull
10% Fowl manure
2% Slaked lime

Building the Pile

Once the ingredients are sourced and their C:N is balanced, pile the materials in alternating layers, thoroughly watering everything as you go. Compost tea and/or compost fungus activator (covered in Chapter 9) can be added to help speed up the composting process. Build the pile at least 4–6 feet (1.2–1.8 m) tall, 5–6 feet (1.5–1.8 m) wide, and with a peak at the top. A larger pile is preferred as it will naturally self-insulate, helping the microbes reach and hold the required temperature range. Place a small piece of plastic over the top of the pile to help retain moisture and heat. Only cover the peak; you don't want to suffocate or overheat the pile. Tamp the pile down with a shovel and insert a compost thermometer to monitor its core temperature. Make the top layer carbon-based to keep pests out and to reduce odors. Build the pile in one day if possible.

Turning a Compost Pile

Within a day or three, the pile's core should reach 145–160°F (63–71°C). It needs to be above at least 131°F (55°C) to kill plant seeds and pathogens. At this point, turning should begin. The pile is turned by moving the middle third to the bottom of the new pile, the top and sides to the middle, and the bottom to the top. This rotation of materials through the pile will help regulate the temperature and ensure even composting. The piles are turned every few days and only when the pile is in the right temperature range. Add water to the material if it looks dry. At all times, the pile should be tightly packed on the outside and loose on the inside. Turn the pile until the material is soft and pliable and has no scent of ammonia.

Once the above criteria are met, the compost is spread out to dry until it has reached field capacity. Compost at field capacity will produce a short stream of water when firmly squeezed but does not leave standing water in containers. A moisture content of 68–72% is ideal. During the composting process the microbes in the pile convert the ammonium and nitrates in the substrate into themselves (i.e. complex proteins). These microbes then become little snack balloons that the fungus eats during its growth. As these microbes grow, they also acidify the compost, lowering its pH to a point that is more ideal for the mushrooms.

Large *Agaricus* farms finish their compost in specially designed and temperature-controlled rooms. The compost is slowly cooled over a period of days to encourage the proliferation of certain microbes that create more available nitrogen in the substrate and ultimately increase yields. This is referred to as "Phase II" composting. While the process does help increase the quality of the final substrate, it is not practical for most small-scale growers.

The book Growing Wild Mushrooms *by Bob Harris includes design plans for building a small-scale electrical hot compost maker.*[20]

Pasteurizing, Inoculating, and Incubating Compost

Once the compost is ready, it must be pasteurized to kill competitor microbes and insects. Any of the methods from *Pasteurizing Pre-Hydrated Substrates* work well for heat-treating compost. Compost substrates are then inoculated and incubated in trays following the same practices described for manure-based substrates.

A variety of commercial products have been developed to supplement *Agaricus* fruiting on farm scale operations where grain spawn inoculation rates are low. These delayed release supplements are added at spawning or casing. Most smaller scale cultivators do not use these supplements as higher grain spawn inoculation rates provide ample nutrition.

Scaling Up

Many *Agaricus* farms make their compost with wheat straw, chicken manure, and gypsum. Heavy machinery is used to lay out the compost in long "windrows" as well as turn and water the rows. Phase II finishing and pasteurization may be done in a converted shipping container fitted with a computer-controlled system that controls the compost temperature by ducting in hot air through a perforated floor. Once cooled, the compost is inoculated by machines using imported grain spawn before being loaded into large trays lined with plastic. These trays are then stacked high and deep to incubate. Casing is often mostly peat moss that is amended with a variety of supplements.

The Fungi in Compost

An article from the journal *Mycologia* compared the fungal communities found in both plant-based compost and worm castings (vermicompost). The plant-based compost contained 118 species of fungi while the vermicompost contained 142 species. Sixty-six species were common in both composts, most of which were in the genera *Acremonium, Aspergillus, Cladosporium, Malbranchea, Penicillium, Pseudallescheria,* and *Thermomyces.*[19]

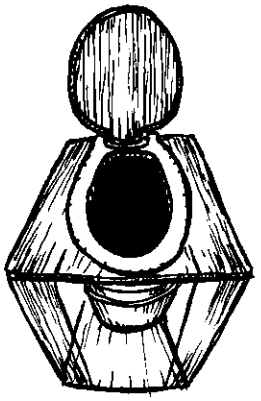
Bokashi Compost

Bokashi composting is an experimental method for producing composted substrates. Here, fresh food scraps are added to a 5-gallon bucket and inoculated with indigenous microorganisms (IMOs) by means of a carrier substance, typically wheat bran. Once the bucket is filled with inoculated food scraps and inoculum, the bucket is left to rest for two weeks. During this time, the microbes proliferate and "pickle" the food waste. The bucket's contents are then buried outdoors for another two weeks to finish the composting process and thereafter retrieved, pasteurized, and used as a substrate for compost-loving species. The result is a high quality compost that took little labor to produce.

As Bokashi compost is generally made from random kitchen scraps, the resultant substrate's nutritional profile and pH will vary by batch. This makes Bokashi undesirable for farm-scale mushroom production where consistency is required. However, considering the ease with which Bokashi is made, it is well worth further elaboration by home-scale growers. Details on obtaining the IMOs and making Bokashi compost can be readily found online.[21]

Humanure

One final substrate that I have had success cultivating compost-loving mushrooms on is one of the most overlooked organic streams in any town or city: human waste. As opposed to fresh human waste, the material I have worked with is the odor-free, nutrient-rich, safe to handle, humus-like end product of composting human waste known as *humanure.*



If you are new to humanure as a concept, this idea may sound a bit strange. But it is not without precedent. Despite the social stigma attached to human waste, many gardeners have promoted the use of humanure as a soil amendment for decades.[22] It is only now that this idea has spread to mushroom cultivation. So, rather than send this nutrient source to costly sewage treatment plants or, as with many cities, out to sea, the adventurous cultivator should consider humanure as merely another overlooked substrate.

If collected from healthy individuals who consume a minimum of antibiotics (including the products of antibiotic-treated animals) and other pharmaceuticals, human waste can be safely composted in two years. In short, most humanure systems revolve around the collection of human solid waste in 5-gallon buckets. After a person makes a deposit, a layer of sawdust or spent mushroom spawn is sprinkled across the material, fully covering the waste to eliminate odors and bug problems. Once the bucket is full, its contents are dumped into a compost bin or 55-gallon drum.

When the container is full, it is covered and left to slowly decompose for two years. At the end of this composting process, the humanure should no longer smell, look, or feel like the parent material that it came from but, instead, like soil. In preliminary experiments, I have found Shaggy Mane and King Stropharia to take well to this material, especially when incorporated with 20% hydrated biochar (by volume) and pasteurized. I believe that other species and formulations will take well to this abundant waste stream, if only the social stigma of working with the initial product could be overcome.

Casing

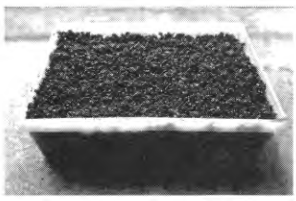
Mushrooms that prefer (faux) compost substrates tend to produce a significantly greater yield when a layer of moist, non-nutritive material is placed on top of the substrate.[23] This layer is known as a casing and provides the following critical functions:

- Being nutrient-poor, it signals to the mushroom that it is running out of food and should produce fruit bodies.
- Its high water holding capacity provides a humid microclimate that assists in the initiation of primordia formation and also serves as a reservoir that the maturing mushrooms pull from to fully develop.
- It helps reduce water loss via evaporation off the top of the substrate.
- For some mushroom species, it provides a bacterial microflora necessary to initiate primordia formation.

Casing pH

Casing layers are made from a variety of highly absorptive, non-nutritive substances such as peat moss, vermiculite, and coconut coir. The pH of a casing is critical as it can impede a fungus' ability to grow properly, significantly reducing yields. Even if all prior steps in the cultivation process were successful, applying a casing layer that is too acidic or dry can ruin the project's yield.

For most species, the casing pH should initially be in the 6.5–8 range. Most casing materials are too acidic and need to have their pH raised with a quick-acting alkalinizing ingredient such as hydrated lime. Casing pH gradually falls to a less than optimal level after the first few harvests due to acids secreted by the mushroom mycelium. Adding a long-lasting, slow-release pH buffer mitigates this acidifying process and extends the harvest.



On Casing Recipes

Peat moss is a main ingredient of most commercial casing mixes. However, peat is overharvested throughout the world, threatening the boggy ecosystems that it grows in. The next best alternative many home cultivators use is coconut coir, though many growers have issues with this material causing excessive overlay. Biochar provides the same functions as these materials and can be experimented with as a casing ingredient.

Example Casing Recipes

60% Vermiculite
40% Coconut coir
Approximately 5% calcium carbonate to raise the pH as needed

12.5 parts Peat moss
12.5 parts Vermiculite
1 part Hydrated lime
3 parts Calcium carbonate

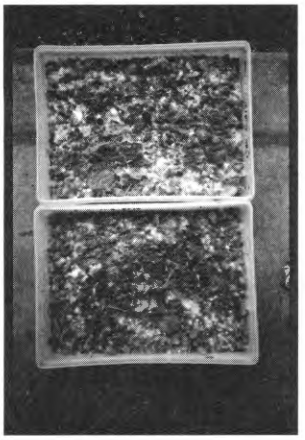
25% Peat moss
25% Vermiculite
30% Hydrate coconut coir
10% Oyster shell
10% Calcium carbonate

4 quarts (4 L) Peat moss
4 quarts (4 L) Vermiculite
1 quart (1 L) Hydrated coconut coir
1 cup (250 mL) Oyster shell flour
5 tablespoons Hydrated lime

Mixing, Pasteurizing, Applying, and Incubating Casing Layers

Casing ingredients (not including pH adjusting ingredients) are hydrated to field capacity separately, combined, and finally pH adjusted using the slow addition of alkalinizing agents. Once the casing is pH adjusted, it is pasteurized using any of the techniques in *Pasteurizing Pre-Hydrated Substrates*. Once cooled, the casing is applied to the trays of myceliated substrates to a depth of 0.5–1.5 inches (1.25–4 cm) for each tray. Deeper casing layers encourage a greater number of flushes but require a longer incubation time. Once applied, casing layers are covered with perforated plastic or aluminum foil and placed back in the incubation space. Over the following week or two, the mycelium will enter and myceliate the casing from below.

The cultivator must pay close attention to the casing and rate of myceliation. The fungus should ideally myceliate the casing evenly. Fruiting should be initiated once the mycelium is just visible across the surface of the tray. If any mycelium surfaces in one area of the tray sooner than in the



Overlay on a biochar-based casing layer.

Some species (e.g. Coprinus comatus*) benefit from deeply scratching the casing prior to initiating fruiting.*

rest of the tray, this visible mycelium should be covered with a small amount of freshly pasteurized casing material to ensure even myceliation. This is known as *patching*. Even myceliation of the casing layer ensures even primordia formation ("pin set") once fruiting is initiated, leading to higher yields.

Overlay

If the cultivator waits too long and does not move the tray to the fruiting space as soon as the casing is evenly myceliated, the mycelium will grow up and over the top of the casing in search of food. Soon, the mycelium will form a hard, dense, water-repellant mat known as *overlay,* which can significantly reduce yields. Overlay can also occur in the fruiting environment due to prolonged high CO_2 levels and/or excessive humidity. If over watered, the overlay will become matted, or will form a dense layer of dead cells on the casing surface.

Casing experiencing overlay will shrink and pull away from the sides of the container. It will also become unreceptive to water and puddles may form on the surface after misting. If any primordia form, they will likely do so at the edges of the casing. Most of the primordia will abort, and only a few mushrooms will fully mature. Once this has happened, the casing layer really isn't a casing layer anymore. It is no longer serving its main functions, and has in essence become a second layer of non-nutritive substrate.

If your casing becomes overlaid, a rescue effort can be made by scratching the surface of the casing to a depth of a few millimeters with a fork or similar device. The entire tray can be also covered in a thin fresh layer of casing in the hopes that the fungus will continue to grow and myceliate this new layer.

The Cobweb Mold of Casing Layers

The fine, gray mycelium of *Hypomyces rosellus* is a relatively common contaminant on casing layers. Commonly referred to as "cobweb mold," this competitor can be treated by the direct spraying of 3% hydrogen peroxide. As cobweb mold is a sign of a high CO_2 concentration, fresh air exchanges should be increased to inhibit further growth of this competitor.

Casing Pin Initiation and Fruiting

Once the casing layer is evenly myceliated but not overlayed (about 1–2 weeks after casing), fruiting should be initiated. Ideally, the casing should be kept at 90–95% relative humidity to initiate primoridia formation. If the casing layer seems dry (e.g. it changes color) at any point during this stage, lightly mist the casing with water. The casing should be constantly moist but not overly wet. Ideally, the humidity levels of the fruiting space will minimize the need for misting.

If all goes well, the mycelium will stop growing for a few days as it establishes itself for fruitbody development. Soon, primordia should begin to appear across the casing layer as many bright white small dots about the size of a pinhead. Once pins begin to form, misting should stop. In several days, the mushrooms will reach maturity and should be harvested.

After your first flush, fill any holes in the casing with freshly pasteurized casing material. Give the casing a good misting at this time until it looks moist, but not saturated. If conditions are ideal, misting should not be needed until after the next flush. If the casing has started pulling away from the side of the container, fill these gaps with fresh casing material. After the first flush you can look forward to the next flush in about a week.

Stage 4: Fruiting

The metabolic shift that causes a mycelial network to condense and form the highly structured mass of a fruiting body is a bit of a mystery. As such, current practices for bringing about this transformation rely on reproducing the environmental changes that trigger fruiting in the wild. These include:

- An increase in the relative humidity.
- An increase in fresh air (O_2) / decrease in the CO_2 concentration.
- A decrease in the ambient temperature.
- An increase in ambient light levels.

The first two factors are the most important in assuring high yields and the full maturation of fruit bodies. In the design of all fruiting spaces, it is best to provide enough fresh air for the mushrooms to breath adequately, but not so much air that the humidity drops and the mushrooms dry out. If humidity levels are not maintained at the recommended levels, primordia may not develop or will abort prior to maturation.

Humidity

As a fruit body swells from a cluster of cells into a mature mushroom, water is lost through evaporation from its surface. If the surrounding air has a low level of humidity, water will evaporate too quickly from the mushroom, inhibiting maturation. Thus, control of humidity in the fruiting space is critical for obtaining a high yield. For many species, 90–95% relative humidity is recommended to initiate primordia formation, while 80–90% is needed for fruit body development. Some woody species (e.g. Reishi) can mature at much lower humidity levels. There are three ways to measure and control humidity:

- **Hygrometer:** Using a high quality human or synthetic hair hygrometer that is certified and accurate within +/- 5% is a fairly accurate and inexpensive means to monitoring humidity levels. Using this meter as a guide, humidity levels are adjusted in the fruiting space according to the designs below. Most inexpensive hygrometers found in horticultural shops are inaccurate at higher humidity levels.
- **Eyeball it/lung it:** Experienced cultivators can learn to tell when a fruiting chamber is in the 80–85% range. This appears as light condensations on the walls of smaller chambers along with an occasional streaking of water. When inhaled, the air inside larger environments should feel heavy and moist.
- **Humidistat:** Devices that measure humidity and control electric humidification systems are used by some larger operations, but they are not necessary for smaller grows. Low cost humidistats tend to malfunction at the high humidity levels required for primordia formation. Expensive humidistats also get damaged by heavy spore loads. That said, some humidistats are better than others and are preferred by growers that wish to invest in this optional device. Shop around.

Air Exchanges

Maturing mushrooms require a significant drop in ambient CO_2 levels and an influx of O_2 to properly develop. This increase in fresh air provides a clear signal that the mushroom should now develop a fruit body to sporulate. As such, this environmental change is considered the main trigger for initiating fruiting. Some species (such as Oysters) require a significantly greater amount of fresh air than other species. Other species, such as Reishi and Enoki, are intentionally fruited in high CO_2 conditions to encourage the development of elongated stalks.

UV light in the 200–300 µm range can adversely affect mycelial growth. This can be reversed by exposure to 360–420 µm light in a process known as photoreactivation.

Lighting

Though mushrooms do not photosynthesize, many species need some amount of light to initiate fruiting and to provide a direction to orient toward. Some mushroom species are stimulated by specific wavelengths of light. Experience has shown that bright light with a color temperature of 5000–7000 K, such as that produced by a 15 watt, full spectrum ("daylight"), compact fluorescent bulb is adequate. Many farms use standard fluorescent tube lights. Lights are generally set on a 12-hour on/off cycle. Indirect sunlight also works as long as the mushroom does not heat up or dry out. Sunlight decreases energy use while also increasing the pigmentation and vitamin D content of some mushroom species. LED strings that produce 6500 K light can also be used. LEDs lighting systems can run off of 12-volt power sources, providing the option for discrete, solar powered, off-the-grid, sealed lead acid battery pack power based systems. LEDs are much cheaper today than they were just a few years ago and, if treated properly, can illuminate grows for years.

Temperature

Many species will grow and fruit at the same temperature, but some mushroom species/strains require a drop in temperature of 10°F (5.5°C) or more to initiate primordia formation. Or, they may need to be placed within a specific temperature range to initiate fruiting. Many species develop a darker color and more umami-rich flavor when grown in cold temperatures.

For the small-scale grower, controlling the temperature of an incubation and/or fruiting space can incur undesirable costs. Simple strategies for helping drop the temperature at fruiting include:

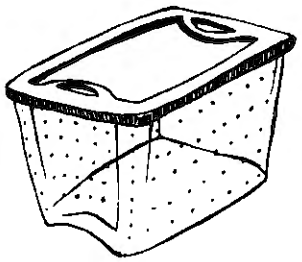
- Incubating spawn above a refrigerator or on the top shelves of a closet where the air is warm. At fruiting, move these kits to a cold room, basement, or shed.
- "Cold shock" the mycelium by placing it in a refrigerator overnight. This is commonly done for some species, such as Shiitake.
- Grow mushrooms seasonally, as noted earlier for Oysters on straw.

Fruiting Environments

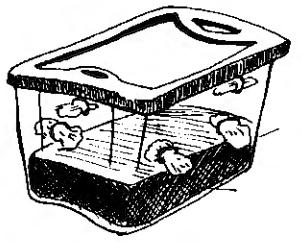
All fruiting spaces must accommodate for the above requirements. As long as these are met, the actual design is ultimately limited by the creativity of the cultivator. That said, several tried and true designs have been developed and refined over the decades to meet the needs and limitations of all operation scales.

Common Options for Small Fruiting Spaces

- **In vitro:** Many species will begin to fruit in their container, signaling to the cultivator that they should be moved to a fruiting space. If these fruit bodies are allowed to mature "in the bag," the need for a fruiting space is eliminated. Mushrooms grown in these high CO_2 environments often develop malformed fruit bodies, an unappealing trait. This discreet, low-input practice is commonly used with Reishi and *Psilocybe cubensis* where the appearance of the mushroom is not as great of a concern. Filter patch bags equipped with a high micron filter or, better yet, a large filter size will facilitate healthy fruit body maturation of other species *in vitro*.
- **Bathrooms:** The humidity of a bathroom makes for an easy and natural fruiting environment for species that can tolerate swings in humidity. Oysters fruiting from towering buckets or hanging bags of coffee and/or straw are nice additions to any modern bathroom.
- **The plastic tent:** This simple fruiting chamber is commonly used for the casual cultivator seeking to fruit one or two sawdust blocks or straw kits/buckets. Here, a plastic bag or piece of plastic sheeting is tented over the fruiting kit to hold in moisture. Fresh air is provided through slits or small holes cut in the plastic. Humidity is maintained by spraying the inside of the bag (but not the mushrooms) as needed to maintain slight condensation on the bag's interior. The kit and bag are placed in an appropriately heated space and light is provided with any of the suggested sources.
- **Outdoor microclimate:** Shaded outdoor areas that supply adequate humidity can often support the maturation of mushrooms on fruiting blocks or containers. Designing these spaces is discussed in Chapter 9.



- **Shotgun fruiting chamber (SGFC):** A large plastic tub is drilled over its entire surface with 0.25-inch (0.6 cm) holes spaced 2 inches (5 cm) apart in all directions. These holes allow for passive air exchange while retaining a high humidity level. Extra humidity can be provided by perlite or biochar that has been fully hydrated by being submerged in a pot of water for a few seconds and then drained in a colander. Once excess moisture has stopped dripping, the perlite/biochar is then used to fill the bottom 5 inches (12 cm) of the plastic tub. Fruiting kits or trays are placed on top of the perlite and the lid is closed. The perlite/biochar releases moisture, providing humidity. The walls of the tub may need to be misted occasionally to maintain proper humidity levels.[24]



- **Monotub:** In this set-and-forget system, substrate is directly inoculated with grain spawn in the bottom of a plastic tub that has been fitted with several 1-inch (2.5 cm) holes. After inoculation, the tub's lid is set in place and not removed until harvest. During myceliation, the holes are covered with duct tape or a similar material to retain moisture and keep CO_2 levels high. Once the substrate is myceliated, the tape is removed and the holes are then plugged with fiberfil to provide an influx of fresh air. The number of holes and the amount of fiberfil used varies by climate and season. Often, all that is needed is just enough fiberfil to keep dust and bugs out. However, if the humidity does not stay high enough in the tub, more fiberfil should be used. Holes are located along the substrate layer and at the top of the container to provide a natural current of fresh air coming in from the top while the heavier CO_2 exits at the substrate level. This system works well for compost-loving species as well as for the species that can be spawned to pasteurized, plain sawdust. Nutrified sawdust should not be used in a monotub as it is likely to contaminate. The lids of monotubs can be modified with a clear piece of glass to facilitate viewing and LED light strings can be added to the inside of the lid to create an all-in-one fruiting environment. Some cultivators mix a saturated and sterilized water holding substance such as coconut coir, vermiculite, or biochar with the substrates at spawning to increase the water content in a monotub and its subsequent yields. This is known as the *rez effect*.

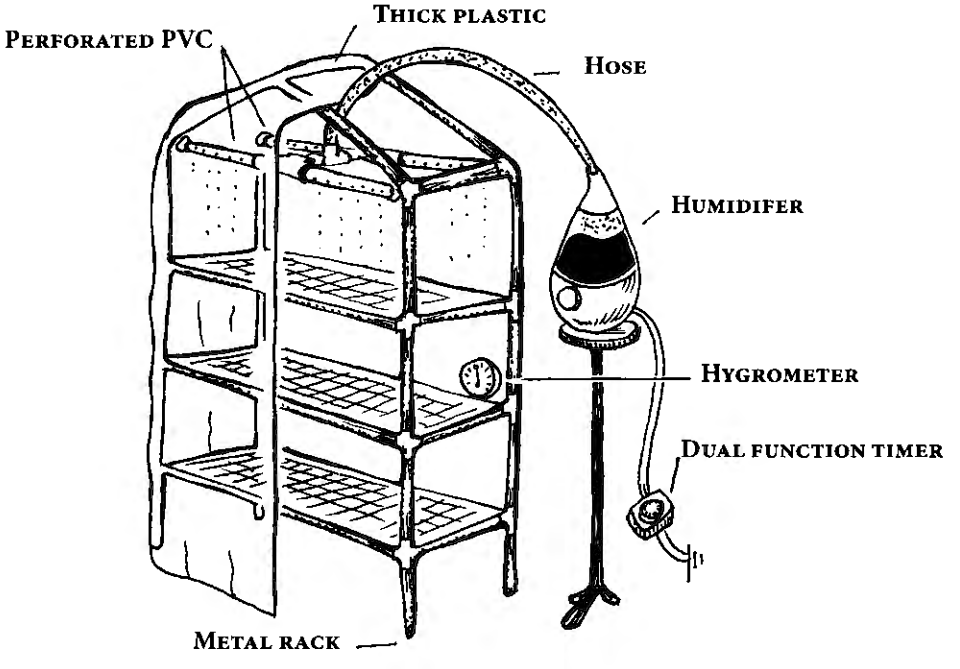
Medium Scale Fruiting Spaces: Automated Greenhouses

The grower wishing to fruit more than a couple kits at a time will want to scale up from the above designs to a larger fruiting space. The most commonly used medium-scale indoor fruiting environment consists of a shelving unit covered in plastic—a homemade or pre-manufactured "indoor greenhouse." Humidity is provided to these shelving units by an electric humidifier and is monitored with a high quality hygrometer. Fresh air is provided by either the humidifier, holes cut in the plastic, or by a small fan. Light is provided by light fixtures or LEDs set on a timer.

Dialing in the correct humidity level and air exchange rate for these systems can be tricky. In a relatively humid climate, indoor greenhouses can be adequately humidified and ventilated with a single cool mist (impeller style) humidifier. The humid air is channeled into the greenhouse by means of a stiff plastic tubing and set to run 24 hours a day, providing a constant source of fresh, humid air to the mushrooms. Inside the greenhouse, an H-shaped structure made from perforated PVC pipe can help distribute the humid air across the top of the greenhouse to then rain down. At the bottom, a tray filled with perlite or biochar can serve as a reservoir to capture/release moisture, while CO_2 escapes through the opening. As these humidifiers often have a relatively small water reservoir, an extra holding tank can be attached to the humidifier to reduce the need for constant monitoring and refilling of the humidifier. The water in this extra holding tank should ideally be filtered or boiled and cooled to discourage contaminant growth. Optionally, 3% H_2O_2 (at 10% by volume) or a few drops of iodine can be added to this reservoir.

If the cool mist humidifier is not achieving the required humidity levels, an ultrasonic humidifier can be incorporated into the system to boost the ambient moisture level. Ultrasonic humidifiers produce a dense fog of humid air and only need to run for a short time to supplement a cool mist humidifier. If an ultrasonic humidifier runs for too long it can oversaturate a casing layer or fruiting kit, increasing contamination rates and reducing yields. The ultrasonic humidifier can either be placed in the greenhouse or the fog can be piped in.

An alternate design involves using the ultrasonic humidifier only to control humidity, and providing fresh air by means of a computer fan installed at the top of the greenhouse. Adjusting how opened/closed the greenhouse door is can also be an easy way to manage air and humidity levels. Numerous iterations to these basic automated greenhouse designs exist online.[25]



Large Fruiting Spaces

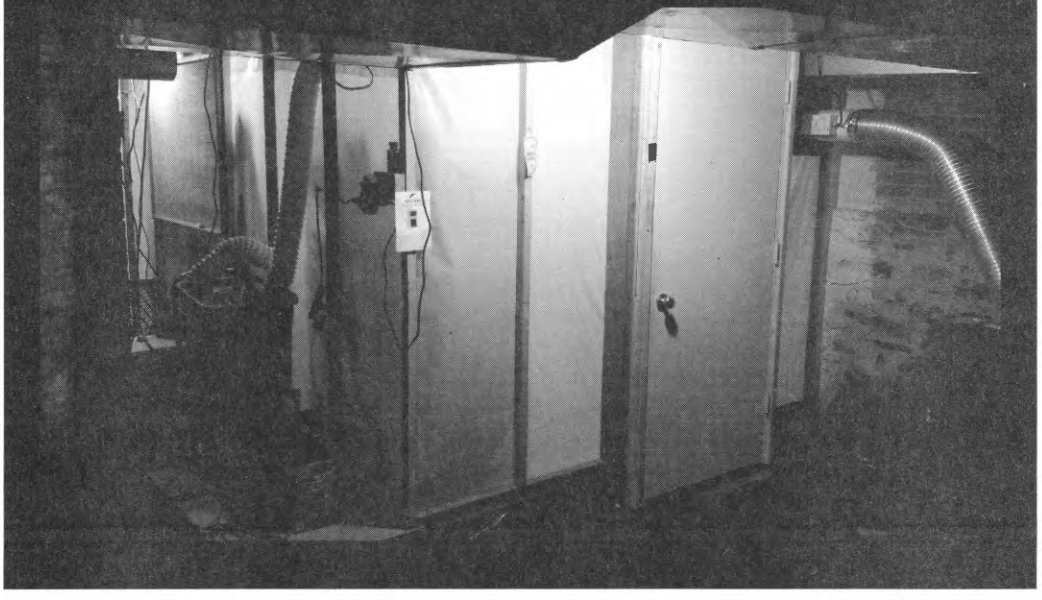
For larger operations, most mushroom farms apply the above concepts to warehouses, shipping containers, and greenhouses. Industrial hydrostats, fogging systems, and/or ultrasonic humidifiers are used to maintain humidity while fresh, HEPA filtered air is pushed into the environment in which CO_2 levels are monitored. Lighting and temperature are also controlled following the fruiting parameters of the given species. Site ideas for large-scale fruiting operations include:

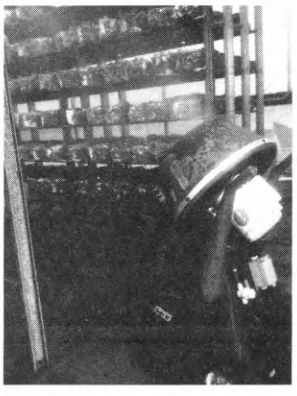
- A cement walled basement with a floor drain.
- The unused, shady, and vertical spaces of a vegetable greenhouse.
- Shipping containers. Buried shipping containers are ideal as they tend to hold ideal fruiting temperatures year-round. A shipping container can also be converted to hold a lab, incubation space, and fruiting environment in the same space.
- Abandoned civic infrastructure, such as subway tunnels, which often have preexisting ventilation and drainage systems.
- Gothic shaped greenhouses or warehouses. Many farms prefer these structures as their shape helps reduce the collection of heat and moisture in ceiling corners. Better yet, sink the greenhouse in the ground.
- Geodesic domes, which are easy to build and modular.
- Hoop houses or greenhouses. Many farms around the world utilize simple outbuildings for fruiting mushrooms.
- A plastic-wrapped, wood-framed room-in-a-room built to any size. It is easier to manage humidity in several smaller rooms than it is in a large one. If funding is limited for multiple humifiers, fans can be used to circulate humid air throughout the fruting space.

For the technically inclined, Arduino-controlled CO_2 monitors and humidistats can be programmed to control ventilation and humidification systems.

The Fruiting Room of Fungi Ally

At this mushroom farm in Amherst, MA, one 16-foot by 8-foot room is able to produce around 70–80 pounds (32–36 kg) of fresh Shiitake mushrooms every week. Fresh air is pumped into the room through a box modified with a HEPA filter. This intake is equipped with an inline heater to raise the room's temperature in the colder months. Humidity is produced by re-circulating the fruiting room's air back through a 12-head ultrasonic humidifier that is pulling in water from an 18-gallon plastic container. This water reservoir is equipped with a toilet float valve and connected to a waterline so that it refills automatically.





Dual Function Timers

An easy way to control the humidity and oxygen levels in an automated greenhouse is with "dual function" timers which, unlike the common 24-hour cycle timers, can be set to turn on and off for variable amounts of time. For example, the timer for a computer fan could be set to turn on for 60 seconds every 15 minutes, while a second timer for the ultrasonic humidifier could be set to turn on for 45 seconds every 10 minutes. Such cycles are often needed to produce the proper air quality in a fruiting environment. Inexpensive 24-hour timers can be modified to act as dual-function timers. All one needs to do is remove a cog from the gear system of these timers, causing it to run faster.[26]

The Fruiting Process

Once you have determined the scale and design of your fruiting space, the next step is to determine how and when to move spawn kits from the incubation space to the fruiting environment. There are two basic options for making this crucial decision:

- **Let the mushrooms fruit:** Some species/strains will begin to fruit in the bag/jar once they have run out of food. Once fruiting is self-initiated, the bag is opened and moved to a fruiting environment set to the proper parameters. For mushrooms that form stalks and fruit vertically, all but 1–2 inches (2.5–5 cm) of the top of the bag is cut off, proving a slightly CO_2-rich environment that encourages longer stalk formation. For mushrooms that form horizontally, the bag is punctured and rolled down, while slits or X-shaped holes are cut in the side of the bag to allow the mushroom to develop unimpeded. These holes should be cut as soon as the substrate is fully myceliated to minimize growth inhibition. Shiitake, *Agrocybe spp.*, Nameko, and Brick Cap can be entirely removed from their grow bags to support the formation of more fruit bodies.
- **Trigger the fungus to fruit:** Some species/strains require a cold shock, overnight submersion in water, or both to initiate primordia formation. Otherwise, changing environmental conditions triggers fruiting.

PF Tek

In 1992, Robert McPherson (a.k.a. Professor Fanaticus) introduced the PF Tek, a simple means for growing *Psilocybe cubensis* using little more than some canning jars, vermiculite, brown rice, and a few spores. This technique significantly lowered the perceived level of skill required to successfully grow mushrooms at home. In the years since its introduction, the PF method has been highly elaborated upon by cultivators around the world, each with their own preferred tweak to the tek. Assuming that the reader has a firm grasp of the cultivation concepts above, I lastly present the PF Tek in a summarized format for the sake of thoroughness and, well, because it's just so ridiculously easy.

Materials

- Half-pint (250 mL) canning jars
- Aluminum foil
- Brown Rice Flour (BRF) (store bought or homemade in a coffee grinder)
- Canning jar lids with 4 holes poked out with a hammer and nail
- Spore syringe
- Tool sterilizing materials
- Vermiculite

Method

1. Hydrate the vermiculite to field capacity. Slowly, evenly, and thoroughly mix in the BRF. The preferred ratio of ingredients is 2:1:1 (verm:H_2O:BRF). For 5 jars, 2 cups (500 mL) vermiculite, 1 cup (250 mL) water, and 1 cup BRF is adequate.
2. Fill the jars with this mix to within 0.5 inches (1.25 cm) of the top. Clean this upper part of the jar thoroughly and then top the jars off with dry vermiculite. This vermiculite serves as a crude air filter.
3. Cover each jar with a punctured lid and foil.
4. Pressure cook the jars at 15 psi for 60 minutes OR steam them in a pot with a heavy lid for 90 minutes. Allow the jars to cool overnight.
5. Under aseptic conditions, inoculate each hole in the lid with 0.25 mL from a spore syringe or liquid culture syringe, replacing the foil or substituting with micropore tape once inoculated. Be sure that the needle is sterile. Many people have success inoculating their jars in a clean bathroom.
6. Incubate the jars until they are fully myceliated. After full myceliation, allow the jars to sit for another week to further condense.
7. Open each jar and knock the "cake" out to "birth" it. Dunk the cakes in cold water for 12–24 hours.
8. Roll the cakes in dry vermiculite and place them in a fruiting space.
9. At harvest, make a spore syringe and repeat.

Cakes typically flush 3–4 times. Yields are increased if the cakes are dunked for 12 hours between flushes. PF cakes can be used as spawn for higher quality substrates such as compost or manure. Shiitake, Oysters, and other mushroom species have been successfully fruited from PF cakes, often with a low BE relative to more robust substrates. If biochar is used in place of vermiculite, this technique presents a very simple, low-cost means for producing small amounts of mushrooms.

Harvesting

For many mushrooms, the ideal harvest time is just before or soon after the cap begins to uncurl or the partial veil starts to tear away from the cap margin. Generally, the smaller the fruit body, the richer its flavor. To harvest, twist the mushroom or cluster off of the fruiting substrate, then cut the stem butt off to dress the mushroom for consumption or market. Cutting the mushrooms in place will leave the stem bottom behind, which can rot and quickly cause contamination problems.

After a fruiting kit produces its first flush, it is generally left in the fruiting space where, within a week or three, it will likely produce a second flush. A third or fourth flush may be possible, but most farms do not use their limited shelf space for these older kits due to the low yield gained from these later flushes.

Pushing the Yield

A few tricks have been developed to get the most mycobang for a substrate buck:

- **Dunking:** Some species/strains will produce a greater yield if submerged in a bath of cold water for 6–12 hours prior to the first flush and/or between flushes.

What Do I Do With Myceliated Substrates When They Stop Fruiting?

Most mushroom farms throw their spent spawn into a large pile (the "graveyard") and passively wait for it to turn into soil over the course of several years. I prefer to get creative and determine how this major output of the cultivation process can serve a variety of functions. The following are my most common applications for spent spawn, some of which are further elaborated upon in Chapters 9 and 10.

- Feed it to worms or other animals.
- Put it in the compost.
- Incorporate it into soil mixes or seed sprouting medium.
- Use it as mulch in the garden.
- Use it as the absorbent in humanure (dry) toilets.
- Turn it into biochar.
- Stuff it in burlap sacs or build a retaining wall for water filtration.
- Digest it with other substances to produce biogas.
- Extract its digestive enzymes for remediative purposes.
- Use it as spawn for more substrates (rez effect revisited).
- Use it as substrate for other species (substrate sequencing).
- Dehydrate and carve it into a functional item.
- Bury it in sawdust or make a spent spawn bed.
- Use it to grow *Trichoderma* compost inoculum. If you don't do anything, it will likely become this anyway.
- Use it to build a fence/wall.
- Put it outside where it may be naturally triggered to fruit again.
- Place it in the path of heavy metal contaminated water to potentially sorb the metals.

This water bath increases the substrate's water content, helping enhance yields. This technique is frequently used for Shiitake as this species produces a hard crust of mycelium that can withstand such a degree of manipulation. Other species that form strong mycelium, such as the Oyster complex, Turkey Tails, Reishi, and even *Psilocybe cubensis*, are also commonly dunked. Most other species cannot easily withstand dunking as their mycelium is not very tenacious.

- **The rez effect revisited:** After flushes have ceased, myceliated substrates can be broken up, mixed with additional nutrients (such as a pasteurized nitrogen source) and/or water retaining additives, and repacked into a vessel. If all goes well, this last ditch effort may result in a remyceliation of the substrate and further yields.
- **Substrate sequencing:** Once a primary decomposer has finished fruiting from a nutrified sawdust kit, a large amount of nutrients remain in the substrate. These spent kits can be broken up, supplemented with a nitrogen source (e.g. 10–15% bran), rehydrated, sterilized, and inoculated with another species to mimic the ecological succession of decomposition. After wood-loving species have been run through the substrate, the remaining material can then be used to make compost for compost-loving species. Examples of sequencing include Lion's Mane/Shiitake/Nameko to Oyster complex/Maitake/Enoki/Turkey Tail to King Stropharia/Shaggy Mane to *Agaricus spp.*

Preserving Genetics and Culture Libraries

To ensure that the strains you work with do not get lost due to senescence or contamination, it is important to routinely back up your cultures at their optimal state of vigor. This aspect of cultivation tends to operate in the shadows of spawn production, where only occasionally does the cultivator visit their culture library to animate tissue samples and spore prints—the fungal germplasm—that give rise to whole mycelial lineages. Properly maintained, culture libraries can provide viable inoculum of a given strain for decades or longer.

Spore Preservation

Unlike the spore prints obtained for mushroom identification, prints taken for cultivation should be as clean as possible. Once your harvest has matured, select a few choice specimens. Unless your mushrooms fruited in a closed and sterile vessel, the prints you take will likely be contaminated to some degree. Similarly, spores from wild harvested mushrooms are very likely to harbor other microbes. To mitigate this contamination issue, the following strategies are recommended to maximize the cleanliness and longevity of collected spores.

Making Spore Prints

Spore prints are an ideal storage form as spores collected on aluminum foil or glass can retain their viability for years or decades if kept dry and cool.

Materials

- Alcohol
- Aluminum foil
- Clean rag / lint-free cloth
- Fresh mature mushroom cap
- Large, heat tolerant bowl
- Scalpel
- Small, sealable plastic bag
- Tool sterilizing materials
- Toothpicks

Method

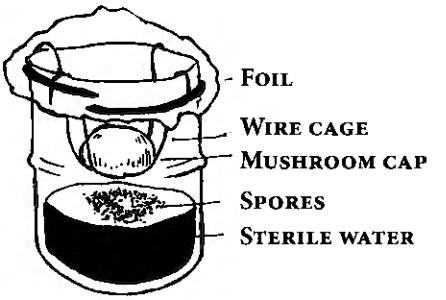
1. Cut squares of aluminum foil to match the quantity of prints you will be taking. These pieces should be 1.5 times by 2.5 times the diameter for the mushroom cap.
2. Fold these foil pieces in half. Place them in the heat resistant bowl along with two toothpicks for every mushroom cap. Cover the bowl with foil. Bake these foil pieces at 350°F (177°C) for 15 minutes to sterilize them.
3. Prepare your transfer space for aseptic work.
4. For each mushroom cap, remove a sterile piece of foil from the bowl and place two toothpicks on top of the foil 1–2 inches (2.5–5 cm) apart.
5. Wipe the surface of each mushroom cap with alcohol. Remove the cap using a sterilized tool and place the cap on top of the toothpicks.
6. Repeat for each mushroom cap.
7. Cover the caps with the bowl.
8. Allow the caps to sit undisturbed for 4–24 hours, or until a noticeable spore load has developed on the foil.
9. Remove the bowl and fold each piece of foil in half and then along all edges so that it is sealed off from the environment.
10. Label the foil with species/strain, date, and harvest site. Place the foil into a plastic bag.
11. Store the bag in a cool, dark, and dry place.

Making Spore Water

Spores suspended in water can easily be extracted with syringes and used as a simple inoculum for grains and other substrates. This is not the ideal long-term storage format for spores as germination may occur inside the water.

Materials

- 1 airport lid
- 1 jar half filled with distilled water
- Aluminum foil
- Fresh, clean, mature mushroom cap
- Scalpel
- Stiff wire
- Tool sterilizing materials



Method

1. Bend the wire to form a crude cage that will fit into the opening of the jar. Fill the jar half way with water.
2. Place this cage in the jar opening and cover the jar with aluminum foil. Wrap the airport lid in foil. Place these items in the pressure cooker and sterilize them for 15 minutes at 15 psi.
3. Prepare your transfer space for aseptic work as the PC cools.
4. Once cool, move the objects into the transfer space.
5. Clean the mushroom cap with alcohol and, as aseptically as possible, move the cap onto the wire cage.
6. Cover the cap and jar with foil and allow them to sit undisturbed for 24 hours.
7. Cleanly remove the foil, cage, and cap. Unwrap the airport lid and seal the spore water jar.
8. Label the jar with species/strain, date, and harvest site and store it in a cool, dark, and dry place.

One of the most charming aspects of the DIY mycological community is its fondness for freely trading cultures amongst growers. Consider contributing to the tradition and swapping strains with other Radical Mycologists as you advance in your practice.

Mycelium Preservation

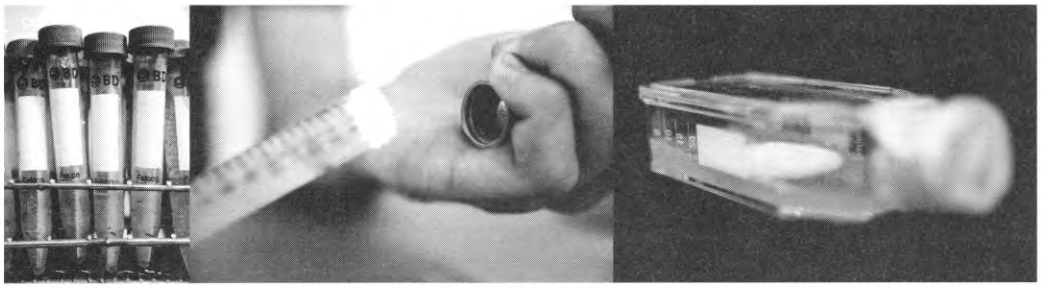
The long-term preservation of a culture is a critical skill for maintaining viable genetic stocks of the species and strains that you work with. The vigor of a mycelial network is at its peak early on in the aseptic practice before it slowly senesces due to a lack of environmental stress. The cultivator should seek to preserve backups ("snapshots") of this early, non-senesced stage by keeping small amounts of the young mycelium in small, refrigerated containers. The quest for balance between space efficiency for the cultivator and nutrient density for the fungus has led to several approaches for mycelium storage.

Slants

One of the most common, but least resilient methods of culture storage comes in the form of test tubes filled with agar that has cooled at an angle. The resulting slanted agar is then inoculated in a manner similar to a Plate-to-Plate Transfer. Media recipes can be the same as those used for agar plates. The agar in slants tends to dry out over time, so a wooden coffee stirring stick that has been soaked overnight can be added to each slant. If the mycelium dies on the dried out agar, a piece of this stir stick, if myceliated, can later be used as an inoculum in an attempt to salvage the strain. Optionally, slants can be overlaid with sterile mineral oil to minimize drying—a rather messy and annoying process. Commonly used tubes include 25x150 millimeter Pyrex test tubes or 15-milliliter polypropylene centrifuge tubes. I prefer to load tubes into a rack and, going one-by-one, dose out 2 teaspoons (7 mL) of dissolved agar media per 15-milliliter tube. A small funnel helps with this filling process. Load the tubes in a wire rack or series of jars, cover them with aluminum foil and PC the tubes for 30 minutes at 15 psi. Once the PC cools, place the tubes at a shallow angle in the transfer space to solidify the slant.

Slants work well as a short-term storage option, but many strains lose their viability in this container within a matter of months. Every six months or so, the culture should be brought out of storage and transferred to an agar plate with a different media formulation than the slant. Once the mycelium begins to grow on the new plate, a piece of leading edge mycelium should be transferred to a new slant containing the same media formulation as the plate and then labeled with the date, species, and media formulation. At this point I place the slants in my incubation space standing upright with their caps minimally screwed down. Once healthy mycelial growth is visible, I tighten the tube's lid, double wrap it with Parafilm, and move it to cold storage to minimize further growth.

Cultivators unfamiliar with the benefits of liquid culture work tend to use slants as the initiator of their mycelial lineages. I reserve slants for emergency storage only and prefer to work with liquid culture mother jars as my primary starter culture.



(Left) Filled slants ready to be pressure cooked.

(Center) After cooking, slants are best opened for inoculation by grasping the lid with a pinky.

(Right) A European strain of Agarikon (Fomitopsis officinalis) gifted to me by a cultivator from Austria in a "slant." Various flat and large-diameter containers are used for storing cultures.

Liquid Culture Mother Jars

Half-pint (250 mL) narrow mouth jars are filled with liquid media and inoculated as normal. Several days later, once mycelial growth is visible and contaminants are not evident, the jars are moved to cold storage. The mycelium will continue to grow slowly in this state but should remain viable for a year or more if kept cold enough. One to two milliliters of this mother LC can be pulled out as needed to start larger LC jars.

Nutrified Sawdust Jars

Small jelly jars or 20-milliliter scintillation tubes are filled with nutrified sawdust, sterilized, and inoculated under aseptic conditions. Once mycelium growth is visible and contaminants do not present, the jars are sealed and moved to cold storage. The mycelium will continue to grow slowly in this state but should remain viable on this nutrient-dense substrate for a year or more. Each piece of myceliated sawdust can work as an easy to remove and viable inoculum source for starting agar lineages.

Sterile Distilled Water

Here, mycelium is placed into small jars or 20-milliliter scintillation tubes that have been filled to their brim with distilled water and sterilized. In the absence of air, nutrients, and minerals, the mycelium will go into a state of suspended animation. These jars can then be sealed and stored at room temperature for years, and potentially decades, without any notable loss in mycelial vigor.[27] This simple, yet incredibly resilient means for preserving cultures was once commonly used in the mushroom cultivation industry. Unfortunately, it has not been well promoted in recent years.

First the mycelium is cultivated on a nutrified agar plate as normal. Once healthy and contaminant-free growth is seen, a piece of leading edge mycelium is then moved to a petri dish filled with distilled water agar (DWA) using a Plate-to-Plate Transfer. Once the mycelium begins to run on the water agar, several pieces of myceliated DWA are moved to a scintillation tube filled with sterile distilled water in the transfer space. The tube's lid is then tightly screwed on and a double layer of plastic wrap is applied. The tube is labeled with date and species, then set on a shelf where it will not be disturbed.

Stopping Early

One of the wonderful, but under appreciated aspects of spawn production is that each of its three stages can be seen as ends in themselves, a concept alluded to in earlier chapters. By stopping at any of these stages the cultivator can bypass the challenges of indoor fruiting yet still receive many benefits from their labors.

- **Stage 1:** As discussed in Chapter 7, several potent medicinal products can be made from the pure mycelium and broth produced during liquid culture work.
- **Stage 2:** Cultivating grain spawn inoculated with liquid culture is the easiest, cheapest, and most resilient means for creating an abundant supply of potent medicinal mushroom products as well as nutritious, protein-, and vitamin-rich fermented foods. Techniques for processing grain spawn for food-medicine are explored in Chapters 6 and 7.
- **Stage 3:** Bulk spawn should not be eaten or processed for medicine due to the nature of the substrates used. However, many cultivators that wish to avoid the process of fruiting mushrooms simply sell spawn that is ready to fruit directly to customers, effectively passing the challenges and costs associated with Stage 4 on to the buyer.

Suggestions for Running a Community Lab

Without a doubt, the many tasks associated with mushroom cultivation are more enjoyable and easier to manage when done collaboratively among a group of equally excited and invested growers. Group projects range widely in their scope and goals. Some are one-off endeavors aimed at growing spawn for a remediation project. Others may seek to develop a year-round fruiting calendar that each group member harvests from in proportion to their time and resource inputs. Regardless of your group's goals, the following advice is offered as a reflection of the common challenges that can arise in such dynamic and multi-dimensional operations.

In the initial learning period, start with a variety of small projects. Work together on these initial projects to collectively understand how successes were achieved and failures arose. From

How I Back Up Cultures

I keep the following on hand at all times: small nutrified agar plates sealed with plastic wrap, larger nutrified agar plates, sterile distilled water jars, distilled water agar plates, small nutrified sawdust jars, and slants that contain a coffee stir stick. I make up small liquid culture jars as needed as they require the greatest amount of storage space.

To create multiple forms of backups, I first clone a mushroom to a small petri dish. This helps to conserve agar in the likely event of contamination during cloning. I also clone to cardboard in case the mushroom doesn't regenerate on the agar. Once a pure culture is obtained (perhaps after several Plate-to-Plate Transfers), I then make six backups from this young culture before moving on to spawn production. First, I inoculate a mother liquid culture jar, as this is the most sensitive backup, as well as a larger LC jar to be used as inoculum as soon as possible. Then I transfer pieces of leading edge mycelium into a nutrified sawdust jar, a distilled water agar plate, and three or four slants. If there is extra mycleliated agar I will also inoculate sterilized grains. Later, when the distilled water agar plate is barely myceliated, I transfer pieces of this plate's leading edge mycelium into small jars of sterile distilled water. All of these backups are kept in a dedicated refrigerator except for the distilled water jars. Replicates of slants are stored off site in the event that the main backups are damaged.

there, set attainable goals and continue raising the bar as those goals are met. Splitting up the tasks of gathering supplies, preparing spawn, doing inoculations, monitoring the incubation/fruiting space, maintaining cultures, facilitating group meetings, fundraising, and increasing community engagement will significantly help reduce the risk of burnout in the group. Setting a schedule for tasks and holding each group member accountable to the work that they sign up for will help maintain cohesion while building trust in the group. Rotation of members is inevitable. To help ensure longevity in the project, at least two to three core members should be identified as bottomliners who will anchor the project's weight as other members come and go.

To make your project self-sustaining, consider selling spawn or mushrooms, teaching workshops, or making the lab a cooperative space where members pay a small fee for access to equipment and fruiting space. A similar model has gained popularity in recent years in the maker culture of 3-D printer users, biohackers, and other creatives. Countless maker spaces have cropped up around the

world in the last decade, each offering a mutual symbiosis for burgeoning community mushroom labs. Through the community lab model, members can Learn-It-Together, Do-It-Together, and Enjoy-It-Together, thereby decreasing the historic trend of isolation amongst mycologists. As the open-source ethos continues to permeate the mycological world, I anticipate that such cooperative mushroom labs will rise in popularity to freely share knowledge of cultivating fungi for the benefit of the world and its people.

On Selling Fungi

Once your have achieved some degree of comfort and consistency with your cultivation practice, you might consider the potential of making mushroom farming a part of your livelihood. While this is certainly possible, many smaller mushroom farms have a hard time fully sustaining themselves, especially in their first few years. The best advice is to start slow, build up your skill set, start marketing early, and ensure that you have established an adequate market for your products before diving in the deep end. Growing through an entire year (or two) on a moderate scale will help you anticipate and avoid major snafus down the road toward larger endeavors.

As the population of cultivators increases in density over the coming years, so will the air of competition that currently surrounds the field. Where the struggles of capitalistic competition can blind one's relationship with their community, other cultivators, or the fungi themselves, growers should consider embodying an ethos often found in the friendly competition of many farmer's markets. Here, the most successful growers are not those that attempt to undermine the success of their peers, but rather the most popular sellers are those that offer the highest quality product. Such efforts to support local economies along with the development of mushroom farm cooperatives will be necessary to truly create a mycophilic culture where the fungi are appreciated, shared, and not abused.

Along with selling spawn, some of the greatest profits for the mushroom grower come from selling mushrooms directly to restaurants or consumers at farmer's markets. Setting up a Community Supported Agriculture (CSA) (or Community Supported Mycoculture [CSM]) program for your mushroom business is a great route for reaching customers. CSAs require participants to pay a flat fee at the beginning of a growing season in exchange for a monthly or biweekly supply of various goods. The CSA model is quite popular among vegetable and meat producers, and in recent years has become increasingly adopted by mushroom farmers. Small mushroom farms often team up with a vegetable CSA. Monthly mycoboxes could contain spawn, medicinal mushroom products, workshop discounts, and mushrooms. Excess or malformed fruit bodies can be dried and/or processed to make value-added products. Get creative!

Advanced Skills

Developing Strains for Novel Substrates

The genetic rearrangement that occurs during the production of sexual spores offers the creative cultivator the ability to develop strains that can readily grow on substrates historically considered unviable. When spores are introduced to an agar formula containing such uncommon ingredients the germination and fusion rates of hyphae directly reflects their tolerance—if not preference—for the given media. While many will fail to thrive, those that persist should all be considered candidates for further strain development. The novel ingredient could be, for example, an agricultural product or an industrial chemical. A generic protocol for such strain development is as follows:

1. Mix several variations of an agar recipe containing the novel ingredient. Have one recipe be comprised entirely of the novel component, agar, and water. If your ingredient is a liquid, use varying concentrations and adjust your water levels accordingly. Other plates can be made with various concentrations of the novel substance, mixed with more commonly used agar ingredients (e.g. dextrose). If you are only making small batches, use small baby food or jelly jars and cook the agar directly in these containers.
2. Under aseptic conditions apply spores of your desired species to the various agar plates.
3. Observe the growth of the strains that develop. If, for example, one strain on the plate that contains only the novel compound grows rapidly and looks healthy, it would be a strong candidate for further culturing. If there are multiple candidate strains, work with all of them at first. Some strains may grow well on the novel agar but are not good fruiting strains.
4. Move the candidate(s) into multiple liquid media jars. This media should contain some amount (e.g. 1%, 5%, 10%, etc.) of the novel substrate as well. These strains can be separated or comingled during this research and development phase.
5. Once run through, apply this liquid inoculum to jars containing the novel substrate. Allow the mycelium to run through the substrate, then initiate fruiting.
6. If you are using a mix of strains, one or two strains may dominate over the rest to grow more vigorously and/or fruit better. Isolate these strains for future projects.

Acclimating Strains

Similarly, cultivators can introduce existing strains to media formulas containing uncommon substrates in an attempt to promote the epigenetic expression of dormant genes. Plates can be made as described for *Developing Strains for Novel Substrates* and inoculated with existing cultures using Plate-to-Plate Transfers or with 1 milliliter of liquid inoculum. If the strain initially displays a low tolerance for the novel substrate, its tolerance for the ingredient can be increased through successive plate transfers, each with an increasing concentration of the substrate. Alternately, the fungus can be initiated on a plate that is half low-nutrient agar and half of the agar containing the novel substrate. If started on the nutrient-poor side, the fungus will surge into the novel substrate in search of food. There are many potential iterations of these themes.

When the tolerance level has reached a maximum, the mycelium can then be transferred to liquid media containing a concentration of the novel ingredient at a rate 10% lower than the predetermined maximum. This decrease in concentration lowers the stress on the mycelium, often promoting a surge in growth. Subsequent grain and spawn formulas should incorporate the novel substrate following the principles of substrate formulation. The rate of application will vary by species/strain and ingredient.

Everything Coffee

A brilliant application of the above concepts has been developed by Geoffroy Grignon of Champignons Maison in Montreal, Quebec.[28] By applying the spores or a tissue culture of a "wood-loving" species to agar media containing coffee, Geoffroy has been able to develop strains of Shiitake, Maitake, Reishi, Lion's Mane, Turkey Tail, and King Stropharia that not only grow on the coffee agar but ultimately fruit off of substrate formulas comprised almost entirely of used coffee grounds. The following is Geoffroy's basic protocol for acclimating strains to this common urban waste stream:

Coffee Agar

Incorporate 2 grams of spent coffee grounds into a standard MYA or PDA agar recipe (1 L). Sterilize the media, pour plates, and inoculate with the spores or tissue culture of the desired species.

Coffee/Grain Spawn

Incorporate 125 grams of spent coffee grounds to 1.05 kilograms of pre-soaked grains. Sterilize the mixture and inoculate with myceliated coffee agar.

Coffee Spawn

Mix up the following ingredients to create ten 2.8-kilogram spawn bags:

- 22.5 kilograms Spent coffee grounds
- 2.5 kilograms Wood chips or curly wood shavings (improves aeration)
- 500 grams Gypsum
- 500 grams Hydrated lime
- 3 kilograms Water (or as much is needed to achieve the appropriate moisture content)

Inoculate the substrate with 200 grams of myceliated Coffee/Grain Spawn (5% inoculation rate). For strains that grow well on coffee, the substrate does not need to be sterilized and inoculations can be done in a non-aseptic environment. Full myceliation is typically complete in 10-15 days, but may be slower the first time the strain is introduced to the spawn mix. Geoffroy has had amazing results with strains of Pink Oyster, Pearl Oyster, Reishi, Elm Oyster, Shiitake, King Stropharia, and Turkey Tails. His coffee-loving Reishi runs through the spawn phase in 5-10 days. After 15 days, the blocks are essentially unbreakable—hammers bounce off of them.

Fruiting Blocks (24 x 1 kg bags)

Once running well on the coffee, Geoffroy is able to grow the mycelium on several generations of coffee spawn before finally fruiting the mushrooms on the following formula:

- 16.15 kilograms Spent coffee ground
- 1.50 kilograms Wood
- 500 grams Gypsum
- 500 grams Hydrated lime
- 3 kilograms Water (or as much is needed to achieve the appropriate moisture content)

He mixes the Coffee Spawn with the Fruiting Substrates in an 80 liter tub at an inoculation rate of at least 15% (around 3 kilograms of spawn to 21 kilograms of the Fruiting Substrate), fills each spawn bag, and then sets them to incubate until they are ready to fruit. These kits can be inoculated in a non-aseptic environment. Some species may not fruit well during their first run through the coffee stages.

The Pros of Coffee

- *Commonly available.*
- *Essentially pre-pasturized.*
- *High density, allowing for a heavier substrate by volume, leading to greater yields.*
- *High concentration of nitrogen and various trace minerals.*
- *Familiar, being one of society's most acceptable addictive drugs.*

The Cons of Coffee

- *It is less stable than wood because of its richness, making it hard to stockpile for more than a week. Freezing is the best storage option.*
- *Aging spawn bags tend to fruit in the bags on their own after around 10 weeks, a potentially undesirable trait.*

Strain Reinvigoration

If a strain begins to senesce, Geoffroy has developed several techniques to increase their vigor. For strains that are generally tenacious (e.g. Oysters), clone a fruiting body produced on one of the coffee spawn bags and repeat the process described above. Successive runs through the cultivation process can increase the vigor of the strain.

For more sensitive strains (e.g. Maitake, Shiitake, and Almond Portobello), the following steps have been shown to increase vigor.

1. Grow the mycelium on the desired substrate.
2. Prepare agar in which 10% of the carbon source (sugar) is replaced with spent coffee grounds. Clone the fungus to this agar.
3. Once myceliated, perform a Plate-to-Plate Transfer, moving the mycelium onto a new plate that now contains 20% coffee in place of the carbon source.
4. Continue to successively increase the coffee concentration through a series of Plate-to-Plate Transfers until the carbon source is entirely coffee-based.
5. Move the mycelium into a liquid medium that does not contain coffee.
6. Once amplified in the liquid medium, inject 15–45 milliliters of the liquid culture onto sterilized coffee/grain spawn.
7. These grains take usually less than a week to myceliate. Geoffroy then continues as described above by going from grain to Coffee Spawn, and then from Coffee Spawn to Fruiting Substrate.

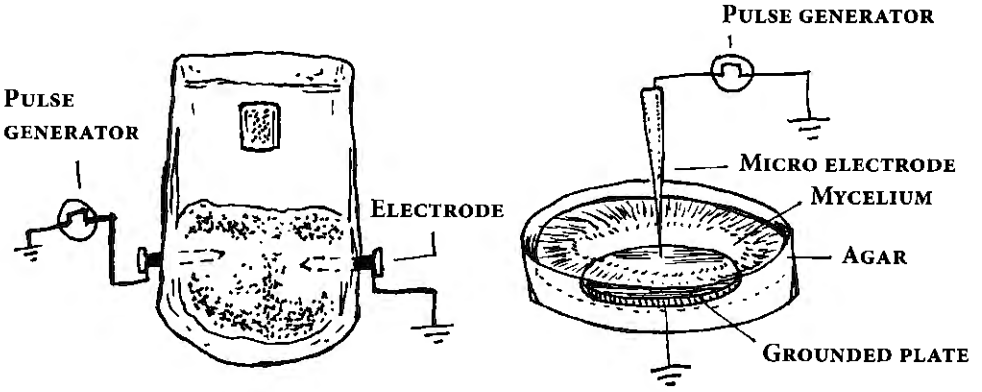
Geoffroy's approach to developing strains deserves a moment of pause, considering its profound implications for addressing many of the issues related to home- and community-scale cultivation (e.g. the cost of substrates). It also provides a clear insight into the unknown future of appropriately applied mycology. By continuing to test the limits of what is possible when working with fungi, cultivators of today can help uncover increasingly more resilient techniques for the application of mushroom mycelium. In the coming years of home mycology and grassroots cultivation research, I anticipate an explosion in strain development practices that will increasingly utilize local waste streams for the health benefits of entire communities, thereby finding solution-oriented approaches to addressing an array of social and environmental issues. What would you like to grow mushrooms on?

(Above) A Reishi mushroom produced from a rock hard block of myceliated coffee-based substrate.

(Left) Shiitake fruiting from a substrate made with over 90% coffee grounds.

The Electric Mushroom

As noted in Chapter 1, mushroom yields can be doubled when short, high voltage pulses of electricity are introduced to myceliated fruiting substrates. Studies tend to find that a single, short (around 10 nanoseconds) burst of 50–200 kV works best. King Oyster, Shiitake, Cauliflower, Nameko, Maitake, Enoki, *Laccaria bicolor*, Matsutake, and many other mushrooms have all shown to be positively affected by these lightning-like strikes of energy.[29] A tool that works well for this purpose is the pulsed voltage generator YHIG-200K-1KJC from Yamabishi Electric Co. Ltd. in Japan. Inexpensive stun guns can produce this strength of voltage, but cannot be pulsed.



Chapter Nine

The Mycocultural Revolution

Comprehend nature, then copy nature. —Viktor Schauberger

Ours is the era of unprecedented change. With major clashes between human activities and the environment becoming increasingly difficult to ignore, a great impetus to create more efficient and ecologically sound living models now confronts the world. In this problem lies a solution that is both exciting for its unlimited potential and challenging for its unknown fate. Beyond peak phosphorus, humanity faces a state of "peak everything" in which severe fuel and water shortages may only be a few short decades away. Global population is predicted to reach 9.2 billion in 2050, a number that cannot be met with current, scarcity-based food and medical systems. And as soil and air temperatures rapidly change and shift natural cycles, fungi are impacted, with the fruiting seasons of some mushrooms now extending to more than double their length compared to averages from the 1950s.[1] Such changes may result in increased decomposition rates, changes in successional patterns, and alterations in fungal symbioses, significant ecological impacts with unknown consequences.

In response to these pressures, environmental and social justice advocates demand the restructuring of governments and the replacement of extractive economic systems with models that accurately account for the cultural and ecological costs of human actions. At the same time, the potential depth of an individual's impact is constantly being reduced through the solution-oriented refinement of alternative food, housing, and social systems that not only reduce inputs and impacts, but also increase vitality in the culture at large. To these grassroots approaches, fungi are proving critical. As the loop-closers and system builders of Nature, fungi expand limits to growth while also providing numerous means for increasing nourishment, self-empowerment, and dignity throughout the design of any resilient living system.

Whereas 80–90% of agriculture's total biomass is currently discarded due to disease or inedibility, mushroom cultivation can convert these "wastes" into food, medicine, and functional items. Incorporated into agropastoral, perennial polycultures, soil fungi significantly increase the yield and integrity of such unified food systems. Through their support of plant growth, mycorrhizal fungi increase the establishment of sensitive and ecologically important flora like native bunch grasses and traditional forage crops, leading to reduced rates of desertification and increased soil stabilization and salinity tolerance. And when integrated into habitat corridors, fungi act as fodder to wildlife, helping reduce or reverse extirpation of important top-down and bottom-up trophic regulators.

By increasing the structural, compositional, and functional diversity of a home or habitat, the efficient, low-input needs of fungi provide novel functions for living systems that seek holistic means to bounce back from disruption, suppression, or shortage. From the elements of natural mushroom farming come processes and integrated living (eco)systems that reflect the connections of a mycelial network. Through this work, the mushroom farmer begins to mimic fungi in their

lives and interactions. In effect, a regenerative culture is grown that can readily synergize, magnify, and celebrate numerous efforts and design systems that increase quality of life. Tending to fungi throughout the seasons, the mycelium becomes the map toward a better future. From nomadic, to horticultural, to agricultural societies, the next revolution in human life will undoubtedly be the rise of the mycoculture.

The 15 Principles of Natural Mushroom Farming and Regenerative Mycology

To begin cultivating fungi outdoors, their ecological habits must be integrated into the principles discussed in Chapter 8. Though outdoor work does not provide for the consistency that indoor cultivation offers, by allowing fungi to engage with the natural environment on their own terms one can engage in the art of ecological co-creation that acknowledges the various relationships and patterns fungi form in the world.

The following 15 design concepts are offered to help influence this work. Largely influenced by the ecologically inspired design system known as *permaculture*, these are not specific protocols, but guiding principles for integrating Nature's patterns into any installation's design. Like mycelium, permaculture designs integrate the features of an environment into a cohesive, efficient, and self-supporting system. By mycomimicking this concept in all aspects of a cultivation project's design, mushroom growers and homesteaders can learn to create personal pathways toward a regenerative future that is supportive of the webs that underlie our lives, our communities, and the ecologies we live within.

Observe and Work With Fungi

This concept applies to all cultivation work but it is especially important to recognize in outdoor installations where control of the environment is beyond the means of the cultivator. Through observation, one can learn to anticipate the success of future installations as the responses of the fungi to their environment become increasingly familiar. When fungi are encountered in the wild, take note of their substrate and the local ecology. Spend time in their home to understand how to recreate it. *This principle is reflected by the fungi in their surveying and responding to environments in ways that reflect the needs or limits of that habitat.*

Catch and Store Energy

The gifts of potential and kinetic energy offered by the Earth and Sun should be honored and collected wherever possible to increase the sustainability and independence of a natural mushroom farming system. Infrastructure and landscaping methods that efficiently collect solar energy, radiant heat, and water should be applied to reduce one's impact on the environment while simultaneously cultivating resilient mycoscapes. *This conservation of energy principle is reflected in the means by which fungi gather and store nutrients in their mycelium and later release them to efficiently navigate and steward their environment.*

Obtain a Flush

Harvesting a large flush of fungi not only brings joy and bounty to the table, it also encourages the cultivator and their students to pursue future cultivation projects. When mushroom installations fail due to poor design or management, it is easy for the beginner to get discouraged and abandon the practice. Tangible yields serve as a visual affirmation of the importance and value of natural mushroom farming and self-sufficiency in general, and help ensure the evolution and spawning of future cultivators. *This principle is exemplified by the fungi through their tireless efforts to always produce and distribute spores, regardless of environmental constraints.*

Apply Self-Regulation and Accept Feedback

Do not assume that you know how a fungus will respond to a novel condition. Experimentation is encouraged with mushroom cultivation, but it is best to maintain a sense of humility as you learn from the successes and failures of innovation. Use these lessons and insights to refine your next experiment. Don't get discouraged, get creative. *This principle is an integral aspect of fungal growth and development. Fungi epigenetically respond to changes in their environment in ways that are self-preserving, energy efficient, and regenerative for the whole ecosystem.*

Use and Value Renewable Resources

Mushroom cultivation is founded on the realization that agricultural "waste" streams can be transformed into high quality food and medicines. Similarly, many other elements and practices used in mushroom cultivation offer a range of outputs that can be creatively utilized. The most resilient mushroom farms utilize solar heat, fermentation, and biogas production when preparing substrates in place of fossil fuels and other non-renewable resources. Nearly every tool used in the cultivation process can be built from reusable materials, lowering costs and cultural debris. Substrates can be sequenced to host a range of species so as to maximize yields. And the fungi themselves can be valued for their variety of regenerative functions, not just for the taste of their fruit bodies. *The fungi reflect this principle in their efficient management and redistribution of resources within an environment.*

Up the Functions

Everything performs more than one function. The science of ecology is based in determining how the various "outputs" of an organism or element affect the environment as a whole. Well designed cultivation systems mimic natural systems by efficiently integrating the various outputs of the design's elements and taking advantage of every output an element has to offer. This concept is often referred to in permaculture as "stacking functions." At all times, consider how a given project or act can accomplish more goals in a shorter amount of time. In most systems currently designed by humans, fungal functions are entirely absent.

Permaculture design utilizes a number of tactics for increasing the efficiency of a living system. Many of these concepts are described in this chapter, in as much as they relate to fungal cultivation. However, these design concepts are only a foundation to build upon. As the field of appropriately applied mycology progresses, new integration strategies are bound to arise that will continue to raise the bar of understanding of what is possible when working with fungi. *This principle is embodied by the fungi in the range of actions that they efficiently engage with in their environment as a unified web of autonomous hyphae.*

Close Loops and Produce No Waste

There is no waste in Nature. To reduce the waste produced by mushroom cultivation, the byproducts of any operation should be utilized by another system on the farm. Contaminated or spent spawn can be employed in a number of ways, as noted in Chapter 8. Where possible, use glass or repurposed tools and containers in place of single-use plastic bags and agar plates. Non-renewable resources and substrates are best used for developing the infrastructure that leads to a self-reliant system. *This principle is witnessed in the fungi's capacity for recomposing the elements of plant and animal matter into the lush topsoil that breeds new life.*

Spawn from Patterns to Details

The various techniques of aseptic mushroom cultivation are based upon the principles and patterns of fungal biology and ecology. This concept readily expands to natural mushroom farming where an intimate understanding of the habits of fungi is needed to best enhance the success of any system. *This endless expansion of life is exemplified in the holographic growth of a mycelial network.*

Myceliate Rather Than Segregate

Everything is connected. The most resilient natural mushroom farming practices integrate fungi into multi-canopied food forests, annual vegetable production, and other installations intentionally inoculated with beneficial microbes. Creating such a diversity of organisms in a landscape not only enhances the overall productivity of a place, it can also stimulate the vigor of the fungus' mycelium and lead to a more robust installation. When the proper mixture of elements are applied to any cultivation system, their combined effect can often be greater than the sum of their individual outputs, enabling even small-scale installations to be highly productive. Recognizing the intimate connection that all life forms share with each other and their habitats imparts a reverence for the brilliance of Nature and the humility to support its longevity for present and future generations. *In natural systems, fungi thrive when they are enmeshed within a dynamic and harmonic ecosystem. Increasing diversity in an ecosystem is an inherent role that the fungi play as keystone species.*

Use Small, Slow, and Simple Solutions

Natural installations with fungi should be seen as long-term endeavors that gradually work to enhance landscapes over time, while occasionally producing crops. When learning to integrate fungi into more complex systems, start small to gain familiarity with your work and then scale up as your understanding increases. When designing installations that emphasize a regenerative or remediative function over fruit body yield, apply caution at first. Work in short bursts (pulses) and in small areas (patches) to observe the effects that your initial design has on the regenerative work that Nature is bringing in of its own accord. Where possible, make the smallest intervention in these cycles as possible.

Mushroom cultivation does not have to be difficult, overly elaborate, or expensive. Installations that follow the principles of natural cultivation and account for the specific needs of a given mushroom species are likely to succeed to some degree regardless of monetary or infrastructural constraints. Once established, well-designed mushroom operations can be self-reliant for years or decades. *This principle is seen in the slow, steady, and powerful march of microscopic hyphal threads as they ramify substrates and enhance ecologies over centuries.*

Use and Value a Diversity of Species and Strains

Each fungal species and strain offers its own unique blend of characteristics to an installation. Integrating a wide variety and number of fungal species, strains, and installations into your design increases the variety of functions offered by the fungi. This not only adds aesthetic and functional value to the land, it also increases the potential for the system to respond and adapt to future changes. Increased diversity and redundancy of species/strains increases one's mycological resilience. Supporting the growth of local fungal strains also helps to increase the geographic distribution and genetic diversity of these strains as their spores eventually spread from your installations along air currents. *The importance of diversity is found in the mixture of fungal and non-fungal species that abound in healthy ecosystems and in the incredible array of genetic expressions offered through the mating of Basidiomycete spores.*

Use a Diversity of Local Substrates and Increase Vitality

Sourcing local substrates reduces the environmental and economic impacts of importation. Developing strains that prefer a locally abundant waste stream or "weed" plant increases a system's resilience. Building soil by growing mushrooms on these substrates supports the cultivation of other crops that can feed animals and produce more substrates, which in turn grow more mushrooms. *The fungi are regenerators of landscapes. They thrive under diversity and in return leave their habitat richer and more fertile than originally found.*

Expand the Edges and Value the Marginal

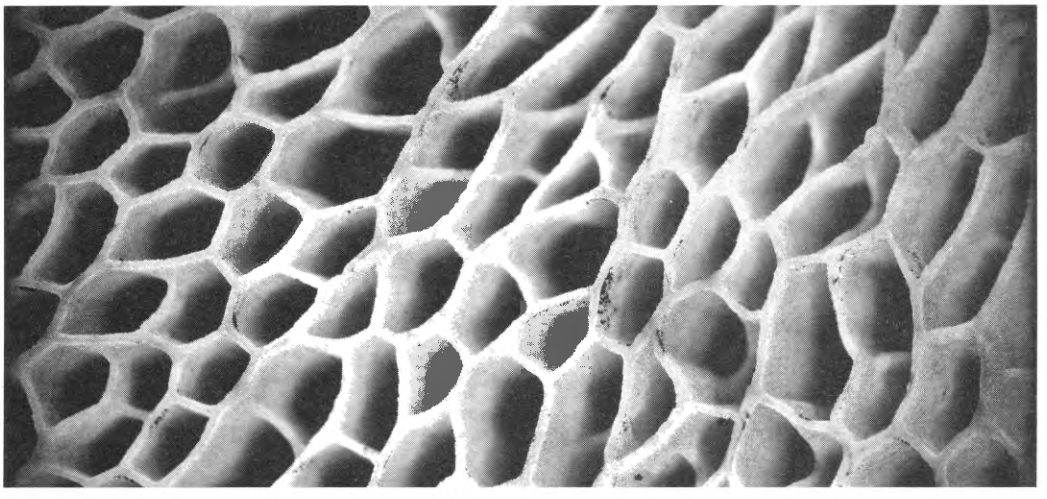
The boundary zone where two environments overlap, known as an *ecotone*, often supports a greater variety of species than the two individual environments on their own. When the total length of a zone's edge is increased through the creation of curves in preference to straight lines, the total available space for edge-dwelling species is thereby increased. Mushroom installations that follow contours and maintain a maximized edge length can support species diversity at a boundary. Marginalized and undervalued fungal species should be constantly reconsidered for any overlooked traits and the underutilized spaces of properties should likewise be evaluated for their ability to support a fungal installation. *The value of the edge in mycology is reflected in the rich diversity and density of fungal species that is often found where two habitats intersect. Mushrooms often fruit on the edges of an installation, where hyphal tips are most active, reflecting the importance of increasing edge length. Mycelium is only one cell thick, giving the network as a whole a very high surface area. Mycelium is almost entirely edge.*

Creatively Adapt to Change

Fungal installations are not static and need regular attention, modification, and/or relocation to maintain their health and vigor. Maintenance can include changing substrates, adding spawn, and improving designs. These modifications should be seen as stepping stones toward developing a familiarity and routine with natural cultivation that can anticipate and prepare for future shifts in the environment. Where appropriate, let Nature take its course in response to changes. This often provides unexpected alternatives to solving a problem. Design systems that are modular and easy to move or upgrade as new needs present themselves. The potential future shortages of fossil fuels and clean water (among many other resources) should serve as an impetus for all Radical Mycologists to design ever more regenerative systems that incorporate the undervalued gifts of fungi. *The fungi are one of the greatest model organisms for the strength and resilience that come from directly confronting and creatively responding to changes in the environment. They thrive under challenging environments and demonstrate the value of pursuing one's goals in the face of adversity.*

Spread Spores

The threads that weave together our contemporary knowledge of fungi have branched from the legacies of countless ancestors. To spawn the next generation of Radical Mycologists, our systems should actively seek to inspire and educate all those that encounter them. The abundance produced should be shared and acknowledged as a symbol of the numerous benefits that fungi provide. *The fungi, as with all the elements of Nature, present an endless array of lessons and insights for how to live in recognition of one's personal impact upon the lives of future generations.*



Natural farming is gentle and easy and indicates a return to the source of farming. A single step away from the source can only lead one astray.
—Masanobu Fukuoka [2]

The Fungal Needs Revisited

Considering the above principles, the Five Fungal Needs presented in Chapter 8 can now be redefined for outdoor work. In general, all natural mushroom farming practices should attempt to account for the following five elements to achieve their greatest longevity:

Substrates
Reflective of the ecological niche of the species being worked with, every species will require either fresh wood, other fresh organic materials, or partially digested substances as a substrate. All substrates should be nutritionally balanced and of the highest quality. To limit resource inputs, substrates should be harvested and processed as close to the installation site as possible.

Water
Installations need a frequent supply of high quality water, especially during the fruiting season. Systems that collect excess water from the environment or a building and channel it to installations are generally offer the most resource efficient means to ensure proper hydration.

Inoculum
Installations can become overrun by a feral fungus if they are not properly implemented. To avoid these humbling moments, the application of fresh, vigorous spawn at high inoculation rates is recommended. Spent spawn is not preferred for most installations due to its decreased growth vigor and potentially suppressed defenses. The use of locally adapted species/strains is emphasized in the creation of resilient installations as their survival rates often extend beyond those of exotic varieties.

Microclimate
A humid environment is required to initiate primordia formation for many mushrooms. In forests and fields, this humidity is provided at the substrate interface by the moisture held beneath understory plants and in the space between blades of grass. To increase warmth and moisture, mushroom installations should be placed under preexisting plant canopies, co-planted with beneficial plants at the time of inoculation, or covered in a thick bed of mulch or other insulating materials.

System
No hypha is an island. Fungi do not live isolated from the flora, fauna, and human systems that surround them. Their strength is found through an interplay with a dynamic environment. Designs should mimic this mycelial bridging by integrating the following skills into self-supporting systems that provide for the needs of the fungus while also enhancing the resilience of the surrounding ecosystem.

These five elements create the container for all mushroom installations. They are the cornerstones on which designs rest, influencing one's relationship to fungi and their perception of the transits between weather, soil, energy, and organism.

Naturalized Inoculum

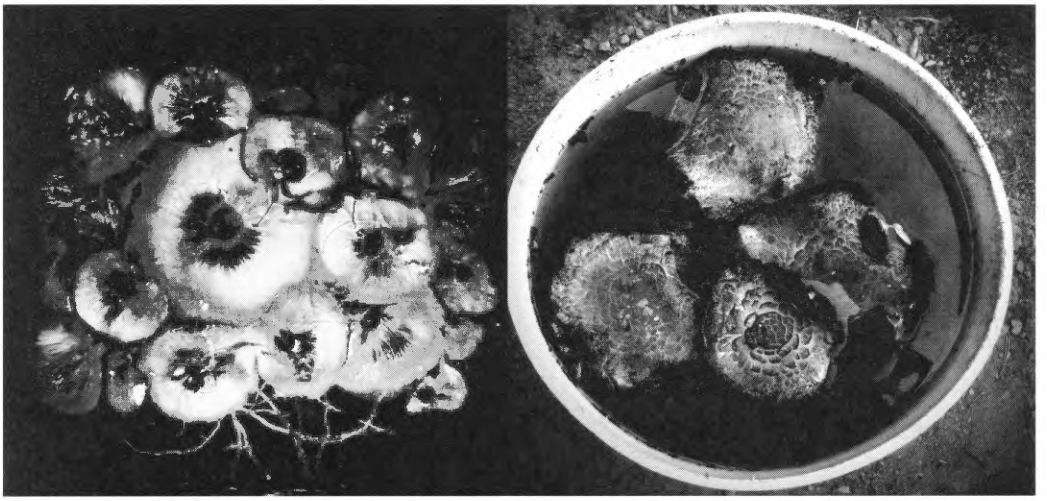
In general, the simplest and most efficient way to create a small number of outdoor installations is with the application of aseptically produced spawn. Despite its various constraints, indoor spawn production provides a reliable means for growing large amounts of mycelium in as short of a time period as possible. However, if one is designing a long-term natural cultivation project, alternative methods for creating inexpensive inoculum are presented here.

Spore Sprays

Here, the spores of desirable mushrooms are collected, placed in water, and then spread across a substrate in the hopes of establishing a mycelial network. This technique is simple, cheap, and easy to apply but, as with all spore work, has an indeterminate outcome. Some attempts will produce vigorous mycelial networks and substantial yields of fruit bodies. Other times, very little is witnessed after months of waiting. Thus, I prefer to apply this technique when working with old or experimental substrates. For higher quality substrates, aseptic or bulk spawn is a better choice of inoculum.

To bulk up a spore collection, develop a habit of collecting spore prints from all of the edible and medicinal mushrooms you harvest or cultivate. As these spores will not be used for aseptic work, their collection can be relatively dirty. Just be sure to keep the spores dry until you apply them, so as to avoid pre-germination. In the spring, scrape these spores into a watering can or sprayer filled with non-chlorinated water, and 2% dextrose by volume (e.g. 2 grams per 98 milliliter water). Allow the mixture to sit at room temperature for two days. During this time the spores will begin to germinate in response to the dextrose. After this incubation period, apply the serum to the desired substrate. I prefer to spray the mixture instead of pouring it, so as to spread the spores farther. Spraying also reduces the chance of the spores being washed away in a heavy flow of water. If you are working with a mixture of substrates or contaminated substances, try combining the spores of different species and/or strains to increase the genetic diversity of the mix and the ultimate chance of obtaining a tangible outcome.

Similar to the concept of developing strains covered in Chapter 8, spore sprays can be applied in uncommon outdoor settings in an attempt to develop strains tolerable of that environment. If luck is on your side, a fruiting strain will arise from a spore spray applied under such conditions. The spores from these first generation mushrooms can then be harvested and applied under the same conditions to create an offspring strain that is perhaps even more tolerable of the new environment than the parent mushroom. This self-selecting breeding process can be repeated over multiple generations in an effort to "speed up evolution" and develop strains that are highly specified to a given substrate or climate.



Cardboard Spawn

Following the basic protocol for cloning a mushroom to cardboard discussed in Chapter 8, large amounts of cardboard spawn can be produced to serve as a low-cost and naturalized mass inoculum. Cardboard spawn is most effectively applied in mushroom beds or to initiate bulk spawn bins. As cardboard has a low nutrient content, co-substrates (e.g. coffee or straw) are suggested at spawning to promote the most vigorous growth.

Bulk Spawn Bins

For large-scale bulk spawn production, I prefer to inoculate large quantities of substrates in plastic tubs and allow them to naturally myceliate for a few months. The simplest approach I have taken in this respect is to mix sawdust spawn with fresh wood chips at an inoculation rate of around 10–20% and then to pack the mix into a container. This minimalist approach to creating bulk spawn works quite well for many of the more aggressive species such as King Stropharia, *Psilocybe* species, and the Oyster complex. For more robust substrates designed to support other species, the following protocol is suggested:

Materials

- Drill and drill bits
- Fresh coffee grounds
- Gypsum
- Hydrated wood chips
- Ink- and tape-free corrugated cardboard
- Large tarp
- Needle and heavy duty thread
- Pasteurized or fermented straw
- Plastic container(s) or burlap sack(s)
- Sawdust spawn
- Soda can and ballpoint pen
- Stiff wire
- Tin snips

Method

1. Place the wood chips in a wire cage or several burlap sacks and soak them in non-chlorinated water for 24 hours. Optionally, add diluted liquid manure or the water left over from hot-water-pasteurized straw to this water. If you add one of these nutrients to the soak water, make sure the concentration is very weak so as to avoid contamination issues.
2. After 24 hours, remove the chips and allow them to drain off excess water.
3. Shred the cardboard into pieces approximately 8x8 inches (20x20 cm) large. Soak these in water for 30 minutes until thoroughly saturated.
4. Lay out the tarp and clean it thoroughly. I tend to just spray my tarps down with water. A very dirty tarp should be cleaned with soap and water.
5. Spread the pasteurized straw and hydrated wood chips on the tarp. Add gypsum at a rate of approximately 1–2% by volume. Break up and sprinkle the majority of the sawdust spawn across the surface of the substrates, reserving a small portion of the spawn for step 7.
6. Lift the ends of the tarp and roll the substrates and spawn back and forth to thoroughly mix them together. Alternately, these materials can be mixed in a substrate tumbler.
7. Strip open the cardboard pieces from step 3 to expose their interior corrugations. Introduce a small piece of sawdust spawn to these corrugations along with a pinch of coffee grounds and gypsum and roll them up in the cardboard like a burrito. Make a dozen or more of these *mycoembers*.
8. Place the mixture from the tarp into the plastic container or burlap sacks. As you do so, introduce 2–3 of the mycoembers.
9. Once the container is full, close the container's lid or stitch the sack closed with a heavy-duty thread.
10. Cut the soda can open and write the species and date on the inside of the can with the pen. Attach the label to the container with wire.
11. Stack these containers on the ground or on a pallet outside and in the shade.

Though burlap can be easy to acquire, it breaks down quickly. Plastic tubs are my preferred means of bulking up naturalized inoculum.

Spawn Run and Maintenance

Like building a fire, the mycelium will quickly jump from the cardboard embers to the straw and on to the wood chips as the mycelium races across the substrate matrix. Wood chips and straw are the preferred substrates as their physical structure allows for relatively deep packing that does not restrict airflow. Small amounts of hydrated sawdust and hydrated biochar can be incorporated as well to provide a variety of particle sizes and water supplementation. The ratio of the substrates is variable—get creative. Depending on your needs, you might add more straw than chips, or vice versa. The former mix provides for faster myceliation, while the latter offers longer viability. Observe a 10–20% inoculation rate if possible.

The container used is also variable. I tend to use large plastic containers as their ability to stack and be reused makes them the most resilient option for low-maintenance systems. Several holes can be drilled in the bottom of these containers to allow for drainage and collection of the fungal exudates and byproducts of decomposition. For very large containers, small holes should be drilled in the sides to allow for passive air exchange. Burlap sacks are a cheap option, but they tend to be consumed by the fungi over time and dry out due to their porous structure. This protocol can also be scaled up to very large containers, such as a large cube made from pallets. For very large or tall containers, PVC pipes drilled with multiple 3/16-inch holes should be placed throughout the substrate to mitigate anaerobic conditions in the substrate core.

Theoretically, as long as the mycelium is adequately fed and challenged, it should continue to vigorously grow for years. Once a single tub is established, its mycelium can be broken up and expanded to dozens of other containers or applied in the distributed installations described below. One tub begets ten, ten beget a hundred, and a hundred become a thousand. Mass applied by Radical Mycologists around the world, this simple technique for producing an abundance of mycelium is one of the most direct means to lowering the barriers to accessing the many gifts of edible and medicinal mushroom installations.

Naturalized Inoculations

Whether you have bulked up mycelium in the lab or in a tote, all saprotrophic mushroom species are inoculated into one of five substrates depending on their natural habitat. These include stumps, logs, wood chip beds, mulch/debris/compost piles, and the ground.

Inoculating Dense Substrates

Logs, stumps, snags, tree rounds, or outdoor furniture items are all viable substrates for long-term installations as their slow degradation leads to more annual yields and minimal maintenance. Once inoculated, these substrates are generally set to incubate for several months. When the substrate is myceliated, it is then triggered to fruit with an influx of water. Cultivating mushrooms on logs is an especially appealing practice for many home growers and small farmers who have a hard time

accessing the wood chips or compost needed for other outdoor practices. Logs are most commonly inoculated with Shiitake, Reishi, Lion's Mane, Nameko, Tuckahoe, Enoki, Turkey Tail, and the Oyster complex (*Pleurotus spp.*). Good candidates for stump cultivation include *Ganoderma* species, Turkey Tail, Nameko, Pioppino, and Oysters.

The wood for all these potential substrates should be of the highest quality (as described in Chapter 8) and appropriate for the species being worked with. The main goal during the inoculation of this substrate is to introduce mushroom mycelium into the cambium layer of the wood (just below the bark), while discouraging the entrance and establishment of competitor fungi. The cambium layer is preferred as the tissue found here is responsible for the transport of water, sucrose, and other nutrients throughout the tree. This vasculature provides the fungi with both a great store of nutrients as well as a "highway" though which the mycelium can easily travel as it permeates the wood. In comparison, the inner heartwood of a tree is relatively low in nutrients and, lacking active vasculature, requires more energy for the fungus to penetrate and ramify.

Fresh logs are the preferred form of dense wood substrate as their consistency in yield has been well established by centuries of use. Logs should ideally be cut down in the late winter/early spring season and inoculated as soon as possible. Logs can rest for up to two months after felling. Any longer is undesirable as the ambient spores of competitor fungi may establish in the wood. If logs must wait to be inoculated, cover any exposed inner tissue with melted wax, clay, or wheat paste to protect them from ambient spores. To keep the logs from cracking and shedding their protective bark, keep them shaded and relatively moist at all times. Nearly any size of wood piece can be inoculated, but the ideal log size is between 4–12 inches (13–30 cm) in diameter and 2–4 feet (0.6–1.2 m) long. Smaller logs do not produce a high yield while larger logs are difficult to manage.

Several methods have been devised to introduce mycelium into the cambium layer of a log (or stump, etc.). A common practice described here is to drill shallow holes and fill these holes with either myceliated dowels (known as plug spawn) or sawdust spawn. Once inoculated, these holes are then covered with wax to prevent the entrance of competitors.

Materials

- Ballpoint pen
- Electric drill or angle grinder
- Empty soda or beer cans
- Log of the appropriate size and species
- Paint brush
- Plug spawn and a rubber mallet *OR* sawdust spawn and a palm inoculator
- Slow cooker or countertop deep fryer
- Soy or bees wax or wheatpaste
- Standard drill bit set or specialty log plugging bits
- Stiff wire or nails
- Tin snip

Mushrooms prefer to grow just beneath the bark of logs where readily available nutrients are easy to obtain.

Method

1. On one end of the log draw several equally spaced marks with a pen to signify the lines along which holes will be drilled down the log's length. For 4-inch (10 cm) diameter logs, mark four lines; for 5–6-inch (13–15 cm) diameter logs, mark six lines; and for 7–8-inch (18–20 cm) diameter logs, mark eight lines.
2. Starting with one of these marks begin drilling holes down the length of the log. Start near the end of the log and space each hole 3–4 inches (7.5–10 cm) apart (approximately fist width). If you will be inoculating the log with plug spawn, use a 5/16-inch (0.8 cm) drill bit and drill down 1.25 inches (3.2 cm). If you are going to be inoculating with sawdust spawn, use a 7/16-inch (1.1 cm) bit and drill down 1.25 inches. An electric drill can be used, though an angle grinder with a modified drill bit works much faster. Specialty drill bits designed for log plugging can be purchased online as well.

3. Once the entire length of the log has been drilled, start down the next line. Stagger this second row of holes in relation to the first row to form a diamond pattern. Repeat this pattern across each row until the log is evenly drilled out. Drill several more holes around both ends of the log.
4. Fill the holes with spawn. If using plug spawn, gently tap the plugs in with a rubber mallet until they are flush with the surface of the log. If working with sawdust spawn, you will need a clean palm inoculator. This tool is used to poke the sawdust spawn, filling its shaft with spawn that is then injected into the drilled hole. If using a palm inoculator, pack the holes relatively densely with spawn but do not cram it in. Leaving a slight amount of aeration in the spawn holes will help the mycelium more readily establish in the cavities.
5. Cover all holes and any areas where bark is missing with a sealant. Melted soy or beeswax are commonly used, but wheatpaste works as well. The wax should be very hot (slightly smoking) when applied to ensure a good seal. This temperature can be quickly accomplished with a countertop deep fryer or more slowly with a crockpot. Covering the ends of the log with wax is optional, but recommended.
6. Label the log with species/strain, wood type, and date. Weather-resistant labels can be made by inscribing information on the inside of an aluminum can with a ballpoint pen. These metal tags are then tied or nailed to the log.

Shiitake mushrooms, though popular amongst farmers in North America, are not indigenous to this continent. Though the potential for this species to establish in the wild has yet to raise concern in the U.S. Environmental Protection Agency, consider working with local species and strains over exotics wherever possible.

Sawdust spawn is preferred over plug spawn as it enables one to easily introduce the greatest amount of healthy, contaminant-resistant spawn per hole.

Spawn Run and Maintenance

Once inoculated, logs are then set to incubate in a shaded, moist location where the drying effects of wind and sun exposure are minimized. Logs can be stacked in open towers but should not be packed too tightly as stagnant air in the towers can encourage contaminant growth. While incubating, the logs must be monitored to ensure that they are not drying out or cracking. Occasional watering with a sprinkler or by immersion in water can help maintain high moisture levels in the logs, especially during warmer months. Ravines, streams, and other water sources provide a naturally cool, moist environment that is ideal for log incubation. Shade cloth can be strung above the logs or laid over them as well to limit sun exposure. For all these shading practices, be sure to create adequate ventilation among the logs to minimize contaminant growth.

Logs need to incubate before they are ready to fruit. The length of this incubation period is dependent of the species/strain of mushroom and wood worked with as well as the inoculation rate, ambient temperatures, and log size, quality, and density. Phoenix Oyster mushrooms grown on alder logs may be ready to fruit within just a few months, while Shiitake grown on oak may require an incubation period of 18 months or longer before the first flush can be initiated. These rates can vary widely. I have met Shiitake farmers who have obtained their first flush from oak logs after only six months of incubation, a very lucky feat.

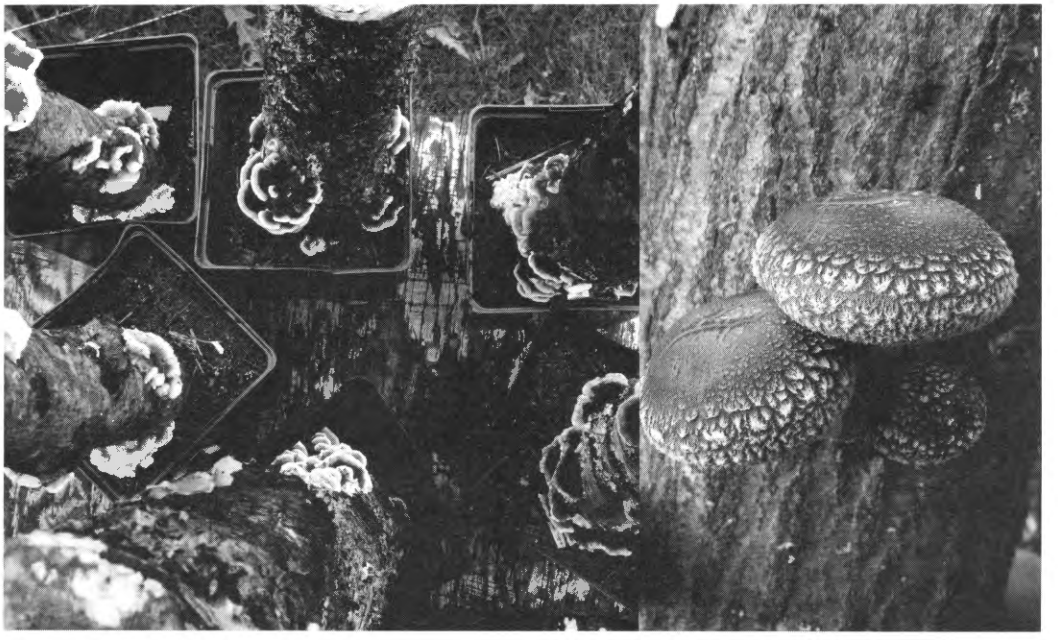
Lands that are gently sloping to the SE in northern hemispheres or to the NE in southern hemispheres tend to have smaller swings in temperature and humidity, making them preferable for log culture.

Fruiting

Larger logs that are difficult to soak can be inoculated with cold weather strains and simply left in an A-frame to passively fruit in the winter months.

After a log has incubated for the recommended wait time—or if you are just curious to see if it will fruit—a flush can be induced by soaking the log in cold water for 24 hours. This soaking provides a large influx of water that supports large flushes of fully developed fruit bodies. Cold water is preferred, especially for Shiitake, as it helps stimulate primoridia formation by simulating autumn temperatures.

After soaking, logs are stood upright on a cross-beam or fence. If the log is thoroughly myceliated, a flush should appear within a week or so. If the log has not incubated long enough, a flush will not appear and the log should be laid to incubate for several more months. Once the first flush is obtained, logs can be laid to rest for a period of six to eight weeks and then soaked again to initiate another crop. This resting/fruiting cycle can be repeated three to five times during the growing season. The fruiting season varies for different species and strains, depending on their preferred fruiting temperature range. Many farms rotate through warm and cold weather strains to ensure consistent production throughout the year.



(Left) Turkey Tails fruiting from short logs potted in sand.

(Right) Shiitake on logs, a time-tested tek.

Making Plug Spawn

If you don't have the means to grow sawdust or coffee spawn, making your own plug spawn is easy. The preferred plug is made from 5/16x1-inch (0.8x2.5 cm) spiral grooved birch dowels used for building furniture. The dowels are soaked for 24 hours in 4% dextrose water, drained, sprinkled with a small amount of gypsum, rolled in wheat bran, and then pressure cooked in a filtered jar for 1 hour at 15 psi. Once cooled, the plugs are inoculated with a small amount of grain spawn under aseptic conditions. Alternately, plugs can be boiled for 20 minutes and then inoculated in the open air with grain spawn in a clean jar with a filtered lid. Plugs should be used as soon as they are well myceliated but not to the point where the mycelium has become a solid mass. Overgrown plugs are not ideal for cultivation as their vigor has likely decreased. If logs are not immediately available, plugs can be stored in a refrigerator for several months to slow growth.

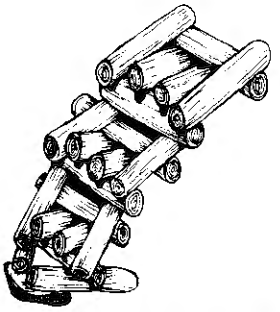
Alternative Inoculation Methods

A variety of other methods have been devised to introduce mycelium to the cambium layer of a log, stump, or tree round. Gashes cut into bark can be packed with sawdust spawn or coffee spawn and sealed with wax. Shallow V-shaped wedges can be cut out of the log, filled with spawn, and then screwed or nailed back together. Stacked tree rounds can be interspersed with spawn and secured with screws or wire. Months later, mushrooms arise from the cut areas.

(Partially) Buried Logs

Logs of several species tend to grow best if they are either fully or partially buried in the ground standing upright. Good candidates for mycotems include Turkey Tail, Reishi, Maitake, and the Cauliflower Mushroom. The logs should be buried in the same orientation that the plant grew, so as to draw water up through the vasculature of the wood and keep it hydrated. In China, Reishi is commonly cultivated on 18-inch (46 cm) logs that are partially buried directly in the ground or in pots filled with clean sand. Once the logs have become myceliated, they are placed under a cloche inside a shaded hoop house. At fruiting, the logs are covered in plastic sheeting to create a high CO_2 environment that encourages a longer stalk to form from the emerging primordia. When the stalk reaches the plastic layer, a hole is cut in the plastic to encourage a shelf to develop on top of the stalk. Collars may be placed around these fruit bodies as well to collect the medicinal spores of the mushroom. These logs tend to produce for two years, at which point they are replaced.

The best method for fruiting Maitake outdoors is to first inoculate and incubate 8-inch (20 cm) oak rounds and then bury them just beneath the soil horizon in a shaded moist area. The sclerotia of *Wolfiporia extensa* are traditionally cultivated by burying inoculated pine logs for two years. However, indoor success has been achieved with this species by inoculating 5x10-centimeter logs in large air-filtered containers. With this method, sclerotia may form after 24 weeks.



This stacking method is commonly used in the steep hillsides surorunding Japanese rice farms to incubate Shiitake logs. In an area that would otherwise be unviable for plant crop production, these logs can be stacked in the hundreds and fruit for years.

Sawdust spawn can directly inoculate logs and tree rounds in a variety of ways. As long as the mycelium gets access to the cambium, mushrooms will (hopefully) fruit. Here, Nameko spawn is being lined into wedge-shaped pockets cut out of logs.

Inoculating Distributed Substrates

Many mushroom species can be established outdoors in piles of wood chips or compost, with the substrate choice depending on the species' niche. The following is my preferred method for installing a woodchip-based mushroom bed.

Materials

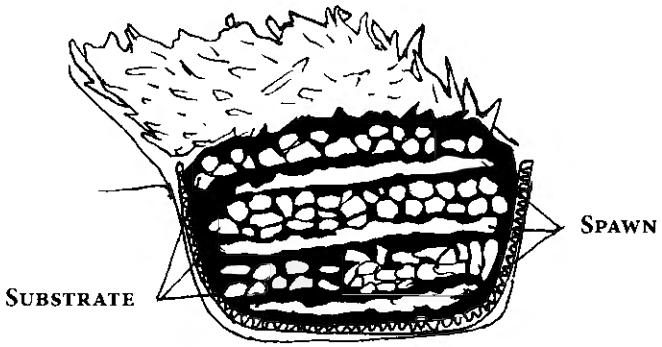
- Biochar
- Cardboard and sharp knife *OR* burlap
- Gypsum
- Hydrated lime
- Sawdust, coffee, or bulk spawn
- Shovel
- Straw or other mulching materials
- Wood chips (optionally soaked in [nutrified] water)

Method

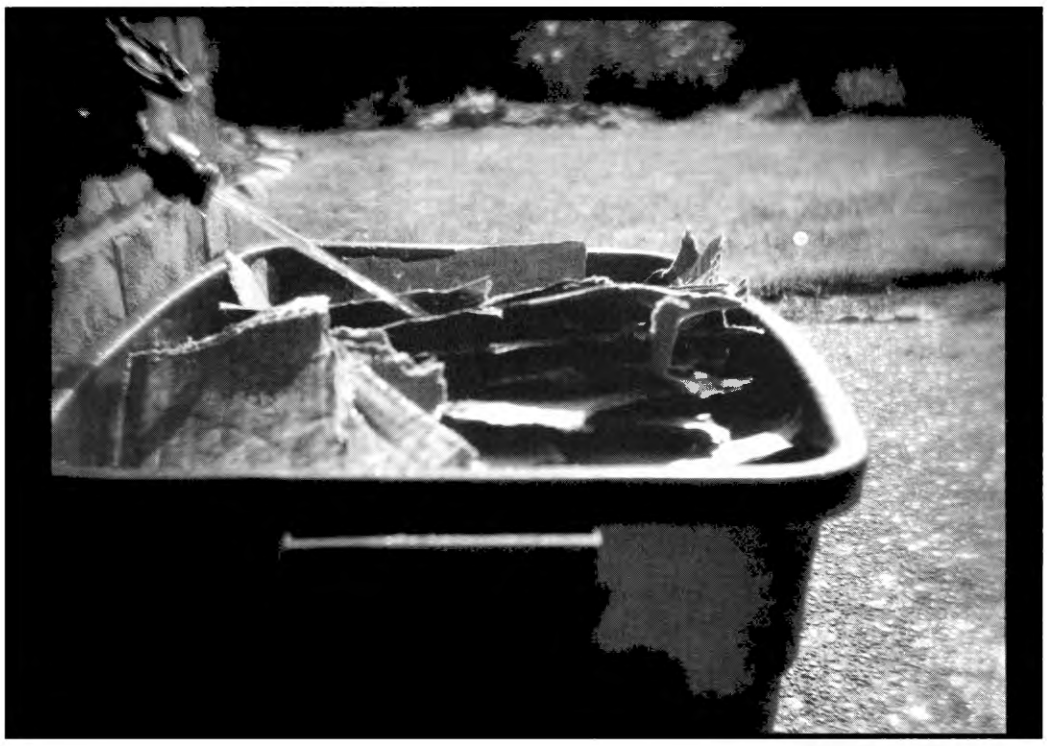
1. Place the wood chips in a wire cage or several burlap sacks and soak them in non-chlorinated water for 24 hours. Optionally, add diluted liquid manure or the water left over from pasteurizing (not fermenting) straw. If you add one of these nutrients to the soak water, make sure the concentration is very weak so as to avoid problems with contamination.
2. Clear the ground of debris and dig out 4–8 inches (10–20 cm) of soil from the entire site.
3. Protect the bed from soil-dwelling fungi by laying multiple layers of burlap or punctured cardboard along the bottom and up the sides of the depression. These materials allow for drainage while also serving as eventual substrates for the mycelium.
4. Add a thin layer of spawn on top of the cardboard. Bulk spawn is arguably ideal as it is naturalized to ambient competitors.
5. Apply 2–4 inches (5–10 cm) of hydrated wood chips.
6. Distribute a thin, nearly contiguous layer of spawn and a light dusting of gypsum and hydrated lime across the wood chips. If you have biochar (discussed later in this chapter) available, soak this material in water or diluted fertilizers and apply at a rate of 5–15% by volume. Thoroughly mix the spawn and supplements into the

wood chips using your hands or shovel.

7. Apply another thin layer of spawn on top of this mix.
8. Repeat steps 5–7 to create a bed that is approximately 8–10 inches (20–25 cm) deep. Optionally, steps 5–7 can be repeated a third time. Beds should not be deeper than 18 inches (46 cm) as anaerobic conditions can occur in the center of the pile.
9. Cover the bed with a layer of mulch to reduce desiccation of the substrate and mycelium. Cardboard and/or burlap can be used as a mulch while the mycelium is establishing itself. Once the fruiting season approaches, these materials should be replaced with 6–8 inches (15–20 cm) of fresh straw. Straw is the preferred mulching material as its structure naturally produces a humid microclimate that helps initiate primordia formation. Straw can be applied at spawning but tends to lose this beneficial structure before the fruiting season approaches.
10. Optionally, once the mycelium is thoroughly established, incorporate a light sprinkling of fresh coffee grounds into the bed several weeks before the fruiting season to supply a nitrogen kick that will support greater fruiting.



My preferred means for installing a mushroom bed is to dig down several inches, line the ground with burlap or cardboard and make a spawn-n-sub sandwich. Topped with mulch and surrounded by microclimate-providing plants, such installations can sustain for several seasons.



Compost / Mulch Piles

For later-stage decomposers, the composted and manure-based materials detailed in Chapter 8 can be used as substrates for outdoor installations. These materials should be pasteurized and cooled before being inoculated in a clean substrate tumbler or on a clean tarp. Once mixed, the materials are formed into aboveground rows on top of burlap or punctured cardboard. These rows are then covered with a low plastic cloche to myceliate and are generally cased once fully run through.

Blewitts, Parasols, and Shaggy Parasol mushrooms prefer grass and yard debris piles. Shaggy Manes are less particular of their substrate and can be established in a range of partially decomposed substrates. Success is less frequent with this species so I tend to take a laissez faire approach to Shaggy patches by burying spawn in semi-disturbed areas or near compost piles along with a mixture of debris and grass clippings.

Incubation and Maintenance

The best seasons for installing wood chip beds are the spring and late summer/early fall, when rains are heavier and temperatures moderate. During warmer months, wood chip beds should be occasionally watered to prevent desiccation of the mycelium and encourage growth. If rainfall is low when the proper fruiting temperatures arrive, several days of heavy watering may help trigger fruiting. Once early frosts set in, cover the bed in an insulating layer of cardboard, plastic sheeting, or mulching materials to help minimize frost damage. Every spring, incorporate a fresh supply of woodchips, coffee grounds, gypsum, hydrated lime, or other amendments to the bed to keep the fungus well fed. Once one bed is established, sections can be moved to other sites to act as inoculum for creating new beds.

Compost rows should be timed to be at full myceliation when the proper fruiting temperatures arise. These beds tend to last one season and only require monitoring of their humidity and oxygen levels to minimize competitors and ensure full fruit body maturation.

Bed Shape

One of the creative elements of a mushroom bed is the fact that it can be created in any shape or size to reflect the contour of the land or to produce a suggestive experience. Beds with an increased edge length also have the opportunity to produce greater yields as many species tend to fruit at the interface between habitats. Further, this increase in edge allows for a denser concentration of companioning plant species and greater species diversity.

(Left) A basic spawn-n-substrate bed gets established in less than half an hour.

(Right) King Stropharia (Queen Stropharia?) is the go-to outdoor mushroom. Not only is it easy to grow, it also produces stool-sized fruit bodes.

Inoculated Log and Woodchip Rafts

Inoculated logs and wood chips can be combined in the ground to form a "raft style" bed in which the logs provide a dense, long-term food source with a high water-holding capacity. Ideally, the logs should be inoculated and incubated as described above and then later buried in the ground and surrounded by wood chips and spawn. However, the logs can be inoculated and the bed built all at once if time does not allow for log incubation. As the fungus myceliates the logs and surrounding chips, the entire raft will become a contiguous network of hyphae thousands of miles long. Experimentation has shown that this practice is most beneficial for Nameko, Reishi, Pioppino, and Brick Cap.

MycoGuilds

If space or substrates are limited, an experimental cultivation technique worth trying is to inoculate a woodchip bed or stump with several mushroom species that fruit at different times of the year. This form of *succession spawning* allows for multiple species to cohabitate in a constrained environment without one species significantly limiting the flush size of their neighbors. Such experimentation may even lead to the discovery of robust *mycoguilds*: specific assemblages of fungal and non-fungal species that complement and enhance the growth of one another. These beds may require heavier supplementation to account for the increase in fungal activity.

Mushroom Bed Cover Crops

Apart from the mulch layer that is typically applied to mushroom beds, additional cover crops of plants can also be seeded into fungal installations at the time of installation. If planted in the fall, cover crops that overwinter can help insulate the bed during the winter months. If planted in the spring, these crops will help provide a microclimate during the fruiting season to encourage primordia development. Potentially beneficial cover crops include:

- Nitrogen-fixing cover crops, such as clover (*Trifolium spp.*) or fava (*Vicia faba*), can be seeded directly into a mushroom bed. When these plants are cut back after several months of growth, the nodules on their roots are released, providing a nitrogen kick to the mushrooms.
- Deep rooting plants ("dynamic accumulators"), such as comfrey (*Symphytum officinale*), can also be planted in or around mushroom beds to provide a dense un-

derstory while drawing up trace minerals from sub soil layers to help supplement the mushroom bed. The comfrey can then be cut back and used as a mulch layer or added to hot compost piles.
- Decorative moss can add an aesthetic element to a bed and potentially serve as a water sink that supports fruit body development.

Fertilizing Mushroom Beds

Along with the annual incorporation of fresh chips and other amendments, a variety of liquid fertilizers can also be applied to a mushroom bed. But, as fungi do not passively absorb nutrients in the same way that plants do, these liquid fertilizers should be held in the substrate for as long as possible and not simply wash through the system. They can also be added to microclimate-providing plants to assist in their growth as well. As a point of experimental departure, I suggest applying the following fertilizers during the spring-fall seasons:

- **Hot pasteurization water:** The nitrogen-rich water left after hot pasteurizing straw and other materials can be diluted by 25–50% and poured onto beds during or just before the fruiting season to serve as a nitrogen amendment.
- **Fermented compost tea:** Fermenting mineral-rich weeds, herbs, and cover crops in water produces a nutrient-dense supplement for plants and mushroom beds. A basic recipe is to fill a bucket one-half to two-thirds full with stinging nettles, chamomile, comfrey, urine, horsetail, and dandelion. Cover the ingredients with boiling water for five minutes, then fill the bucket the rest of the way with cold water and allow it to ferment for one week. Filter out the plant matter and dilute the final tea to 25–35% concentration. Adjust the pH as needed. Spray this mixture onto the beds to effectively kill all the anaerobic microbes.
- **Biodynamic preps and vortexed water:** The application of these various mixtures (discussed later) add nutrients as well as unique energetic signatures that raise the life force of the fungi and their habitat.

Outdoor Competitors

The appetizing mushrooms and substrates found in outdoor installations invariably attract a variety of hungry competitors. Whether you choose to feed the wild or wish to find a middle ground for getting everyone's needs met, dealing with these frienemies is just another joyful aspect of natural mushroom cultivation.

Slugs

If you grow mushrooms outdoors, you will inevitably end up farming slugs as well. In an approximate order of preference and effectiveness, the following methods can be used during the fruiting season to reduce slug populations that will otherwise plunder a harvest:

- Create a "duck run" around the installation where ducks can freely roam and eat the slugs, reducing their population. Keep the ducks away from the mushrooms as they like to nibble on the fungi as well.
- Rake up debris piles where slugs hide during the day.
- Go slug hunting at night.
- Sprinkle a thick ring of diatomaceous earth around the installation or lay down copper wire. Crossing either of these materials harms slugs.
- Surround the area with angular gravel.
- A biodynamic slug spray calls for collecting 50–60 slugs when the Moon is in Cancer and placing them in a closed bucket of water. When the Moon is in Cancer again, strain the liquid and spray it on the borders of installations. Make another batch and apply the following month. Repeat three times at four-week intervals.

Mammals

Deer, squirrels, and other animals are also attracted to the alluring scent and flavor of mushrooms. If these critters are especially ravenous in your area, building a protective fence or cage around the installation may be the best option for dealing with these nosey neighbors.

Other Mushrooms

If substrates are not of the highest quality or the best practices were not followed during installation, feral fungi can make an unexpected and permanent home in your installations. Turkey Tails and Split Gill mushrooms are common competitors on logs while *Coprinus* species like to make a home in woodchip beds. Once established, there is not a simple mitigation strategy for removing these fungi. Good thing most fungi are medicinal.

Spent Spawn Beds

A simple means of pushing the yield from spent kits is to bury them in the ground using the same design principles for fresh wood chip beds. Even contaminated blocks can be buried and potentially continue to produce yields. The main difference here is that pasteurized straw is usually the primary substrate. However, feel free to experiment and add other substrates. This technique is recommended for Almond Portobello, Button (*Agaricus bisporus*), *A. bernardii*, Milky Mushroom, Shaggy Parasol, Reishi, Elm Oyster, *Lentinus squarrosulus*, Parasol, *Morchella spp.*, *Pleurotus spp.*, and Turkey Tail.

Mycorrhizal Cultivation

Along with the saprobic species emphasized thus far, the design principles for cultivating fungi can also be applied to growing mycorrhizal species. When applied to land management systems, the critical functions that these fungi provide to support micro and macro ecologies of an ecosystem or garden can be maximized, often with relatively low cost and complexity.

Presented below are some of the simplest yet most effective means for cultivating mycorrhizal fungi. Depending on the plants being cultivated, the choice of mycorrhizal fungus will vary. Consider the following:

- **Arbuscular mycorrhizal fungi (AM):** AM are non-mushroom-forming generalists that can associate with 80–90% of all plant species in the world. Easily cultivated and applied in landscapes, AM provide an array of benefits to the soil and plant communities that they connect.
- **Ectomycorrhizal fungi (ECM):** These fungi tend to be specialist symbionts, with many only preferring to connect with a small range of plant hosts, usually trees. Many ECM species produce fruit bodies in the wild. However, intentional fruitings of most gourmet ECM mushrooms are not yet possible due to an incomplete understanding of the factors that influence a given species' fruit body development. Some ECM fungi are not very host specific, are easy to cultivate, and can also be induced to fruit.

In general, the inoculation of any plant with AM fungi is encouraged, especially if the inoculum is comprised of locally adapted species/strains that are known to associate with the target plant in the wild. Four plant families do not form mycorrhizae: the Brassicaceae, Amaranthaceae, Caryophyllaceae, and Chenopodiaceae. The different types of cultivated mycorrhizal fungi and their preferred plant partners are listed in Appendix H.

Cultivating Arbuscular Mycorrhizae

The mycelium of AM fungi cannot be cultivated in isolation; they are obligate symbionts that must be grown in symbiosis with plant tissue, typically by introducing AM spores to the root system of a plant. The plant should be in a nutrient-deprived state as this will encourage the plant to accept the fungus as a beneficial partner.

If successful, the mycorrhizal symbiosis should establish in a short time, at which point the partnership is left to grow in a container for several months. At the end of the growing season, the plant is cut back, sending a signal to the fungus that it should produce spores. The following spring, the growing medium is harvested from the container as it is now filled with mycelium, myceliated root fragments, and spore packets. All of these components are viable AM inoculum for future plant crops.

Due to the expense of producing, transporting, and applying high quality AM inoculum—along with the uncertainties of introducing foreign species/strains—broad-scale cultivation is not currently practical on an industrial scale. Smaller scale, on-site production of locally-adapted AM inoculum is a much more appropriate and resilient practice for the average gardener or farmer.

Materials

- 16 7-gallon (26.5 L) Plant containers
- 16 cubic feet (0.45 m^3) Vermiculite
- 240 cubic inches (4,000 cm^3) Coarse (swimming pool filter) sand
- 4 cubic feet (0.11 m^3) Compost
- Seedling trays or conical plastic pots
- Seeds of a suitable plant
- Wild harvested soil

Method

1. Four months before the last frost date, germinate the plant seeds in vermiculite or a clean seed starting mix.
2. One month later, mix the soil and sand at a ratio of 1:3 by volume. The soil should be collected from an intact soil system that hasn't been disturbed in at least two years (such as a forest, wood lot, or fence row). Collect samples from five different sites to ensure that a diversity of AM species is obtained. Collect samples from the top 4 inches (10 cm) of the soil and screen the soil to remove large roots and rocks. If the only available soil has been heavily cultivated, fertilized, or tilled in the last two years, sterilizing this soil might be necessary to avoid the propagation of pathogens.
3. Transplant the seedlings into small pots or cone cells filled with the soil/sand mixture.
4. After the last frost, fill the grow bags or pots three-quarters full with compost and vermiculite (mixed at a ratio of 1:4 by volume). If biochar is abundantly available, you can experiment with substituting some or all of the vermiculite with this medium.
5. Add 0.5 cups (120 mL) of field soil to each container and mix thoroughly.
6. Transplant five host plants into each container. Place the containers in an area where weeds are well controlled.
7. During the growing season, water the plants and weed as needed.
8. At the end of the growing season allow the plants to die from frost. If the plant is cold tolerant, cut it back at the root level. Leave the containers outside over the winter.
9. The following spring, cut back and discard any plant matter from the tops of the bags.
10. Harvest the roots from the soil mix and chop the roots to 1–1.5-inch (2.5–4 cm) segments. Save the soil mix and root fragments.

The most commonly cultivated AM species are in the genera *Glomus* and *Gigaspora*. This is due to the global distribution and climatic tolerance range of these species as well as their minimal

requirements for successful cultivation. *Gigaspora margarita* probably has a worldwide distribution. Studies suggest that working with a blend of AM species incurs greater benefit to the soil ecology and overall plant health when compared to inoculum that uses isolated species. This is likely due to differences in each morphospecies' growth pattern inside the plant tissue, mode of spatial exploration for phosphorus in soils, level of glomalin production, and in their ability to induce growth responses in different plant species. Compared to imported species/strains, locally-adapted AM fungi seem to be more effective at promoting plant growth, especially when applied to the same plant species that they associate with in the wild.

This is a modified version of an AM production protocol designed in a joint venture between the USDA and the Rodale Institute. This basic technique has been shown to create a concentration of 465 fungal propagules per cubic centimeter, a 7,000-fold increase in the field soil's baseline AM concentration.

Which Plant Partner?

The plant host for AMF should be able to form the AM symbiosis and not be of the same family that the inoculum will be eventually applied to in the field or garden, so as to avoid the spread of pathogens. Deep rooting, quick growing grasses are an easy and low-cost option. The tropical grass *Paspalum notatum* is fast growing and has a low tolerance for frost, increasing greater spore yields and decreasing the likelihood of it becoming invasive in colder climates. Local grasses can also be used but should be thoroughly cut back and have their watering stopped at the end of the growing season, thereby ensuring that the plant dies and that the highest spore production is encouraged in the fungus. A combination of plants may support the development of a wider range of mycorrhizal species. Such a combination of plants could include a grassy species (including cereal crops), an allium (e.g. onion or leek), and a legume (e.g. beans, peas, lentils, alfalfa, or clover).

Compost Quality

The phosphorus and nitrogen concentration in the compost used for step 4 can significantly impact the rate of mycorrhizae formation. Composts made primarily from yard clippings (such as those from municipal composting facilities) or dairy manure and leaf compost tend to be high in nitrogen, low in phosphorus, and with moderate potassium levels, leading to a higher rate of mycorrhizae formation. Composts that are high in phosphorus, low in nitrogen, and have moderately high potassium levels must be diluted to rates of 1:19–1:49 to ensure that the plant is not over fertilized.

AM Inoculum Storage

It is unknown how long vegetative hyphae survive in root fragments.[3] As such, it is recommended to apply AM inoculum directly to crops in the spring to maintain the highest concentration of living propagules. Inoculum can be dried and stored in a cool, dry location until use. It is best to use the inoculum within six months but it can potentially retain viability for two to three years. AM spores are more resistant to environmental stress and desiccation than their mycelium. However, spores do not produce mycorrhizal associations as quickly as the mycelium of living mycorrhizal root fragments.

AM Application

Mycorrhizal symbiosis will only form if the AM inoculum is in close proximity to the roots of the host plant. The easiest way to apply the inoculum is to mix it into planting soils and composts at a rate of 5–10% by volume. Depending on the dilution, the above protocol will produce between 200 and 400 cubic feet (5.6–11.3 m^3) of planting medium.

Creating a phosphorus-deprived environment for plants will encourage the formation of mycorrhizae. If you are using an organic planting mix that typically requires phosphorus fertilization, use materials that are low in phosphorus, such as fish hydrolysate. Chemical-based phosphorus fertilizers should be applied at a rate of 3 ppm or less for no more than three times a week.

Applying Compost Tea

Many of the AM species found in genera other than *Glomus* and *Gigaspora* have not been successfully cultivated. This is likely due to a limited understanding of their environmental requirements.[4] Other studies have shown that AMF spore germination is decreased in sterile soil and increased in the presence of microbes.[5] As such, I suggest the application of actively aerated compost tea

(discussed later) at the time of inoculating plants with mycorrhizal fungi. Part of the ingredients used to make the tea should include soil sourced from the natural habitat of the AM species being worked with. This will help bring in the nitrogen-fixing and phosphorus-solubilizing bacteria that are intimately linked to the AM symbiosis.

Testing Efficacy

Before any large-scale application of AM inoculum is applied to a landscape, it is recommended to determine the various impacts that it will have on a living system as well as the degree of maintenance that its introduction will require. Small test plots can be established to monitor the rate of mycorrhizae formation, the assemblage of indigenous AM and pathogens before and after inoculation, and the effects of tillage and fertilizer application over short- and long-term intervals.

Several weeks after inoculation, harvest the roots of several plants to check for the formation of mycorrhizae. Mycelium may be visible to the naked eye. Arbuscules can be detected under a microscope using the staining practices described in Chapter 4. If plant fertilization must be increased, monitor the percentage of mycorrhizal associations over time as an increase in phosphorus can cause plants to eventually reject their mycorrhizal partners.

Cultivating Gourmet ECM

Boletes, Chanterelles, Matsutake, and *Russula* and *Lactarius* species, among many other gourmet woodland mushrooms, form ectomycorrhizae. Considering the price tag attached to these fungi, researchers have attempted to cultivate them under controlled conditions for years. To date, however, yields have been sparse and largely unsuccessful, likely due to an incomplete replication of the dynamic interactions that occur between the plant, fungus, and other microbes in the rhizosphere. While there are no current sure-fire ways to cultivate gourmet ECM, two simple experimental methods are as follows:

Plant and Transplant

1. Identify a wild tree that is known to produce the desired mushroom. This can sometimes be determined by the fact that the mushroom is fruiting from the base of the tree. However, as root systems as well as mycelial mats extend in all directions it may be difficult to determine exactly which tree a given mycorrhizal mushroom is associating with. Use your best judgment.
2. Plant a sapling of the same species in close proximity to the host tree. Be sure to observe best practices for forest management throughout this process.
3. After two or more years, transplant the sapling to your desired location.
4. At the time of planting, apply aerated compost tea (discussed later) that has been inoculated with soil gathered from the base of the original host tree. This will provide soil microbes from the host tree to your new planting that may be required to initiate fruiting. Adding fish bones or rock phosphate nearby will provide a source of phosphorus, which the fungus can channel to the plant, encouraging the sustainment of the symbiosis.

Spore Sprays

1. Obtain a tree sapling of a species that is known to associate with the mushroom you wish to grow.
2. Create a spore spray as described earlier.
3. Plant the sapling in a properly lit location. Spread the spores around the plant roots.
4. Follow step 4 for *Plant and Transplant.*

ECM Spore Inoculum

Most commercial ECM products do not contain gourmet mushroom species, but other fungi that are easier to propagate, are known to form associations with a range of plants, and are easily harvested in the wild. These include species from the genera *Pisolithus, Rhizopgon, Laccaria, Hebeloma,* and *Suillus.* One of the easiest ways to create an inoculum with these fungi is to harvest their fruit bodies, thoroughly dry and pulverize their hymenium, and then sift out the spores. Alternately, fruit bodies can simply be crushed and spread over a landscape at a rate of 2–3 grams per square meter. Puffballs should ideally be harvested just before the fruit body opens. Spores can then be stored at 39°F (4°C) and applied at the time of seed germination or transplanting crops. To create a root dip, suspend the spores in a sticky, clay-based slurry.

Pisolithus tinctorius is one of the most commonly applied ECM species as it can establish with over 50 tree species. It grows quite well in poor soil and sandy areas and it can tolerate a wide range of conditions, including a pH range of 2.6–8.4. However, it does not prefer very wet or temperate locations. Edible and medicinal *Laccaria* mushrooms are commonly applied to trees. Pine trees (*Pinus spp.*) inoculated with *Laccaria laccata* can even be grown indoors and initiated into producing a year-round harvest of mushrooms. After inoculation, the pines are grown under an 18-hour lighting cycle for a period of months until the plant and symbiosis are well established. The light cycle is then shortened to nine hours per day, triggering a state of dormancy in the plant and the fruiting of the mushrooms. If conditions are right, the mushrooms will continuously fruit for 15 months, yielding a bounty that can surpass the weight of the host tree.[6]

Aseptic ECM Cultivation

ECM inoculum can also be produced using the aseptic practices covered in Chapter 8. Unlike AMF, which will not grow without a plant associate, the mycelium of many ECM fungi can be cultivated in isolation. Species in the genera *Boletus, Hebeloma,* and *Laccaria* can be readily grown on complex agar or in liquid media (e.g. MMN, PACH, or FDA). Sometimes the liquid media is slightly solidified with the addition of 0.3% agar. *Amanitas, Cantharelllus,* and *Lactarius* species, as well as truffles can also be grown aseptically, but they require media formulas that are very precise. Some genera grow more rapidly than others.

For forestry work and experiments, ECM mycelium is usually amplified in a liquid medium and then applied to a plant's root zone. The culture can simply be poured directly, or the mycelium may be filtered out with a coffee filter, washed briefly in sterile water, and then immediately applied.

Isolating and Identifying Mycorrhizal Spores

Commercial mycorrhizal inoculum products are often produced by obtaining wild or pot-cultured spores, cleaning and counting these spores, and then mixing them at a set dilution ratio with a carrier substance such as clay. The cost of this preparation is ultimately passed on to the consumer, making commercial products a relatively expensive option when compared to the cost and ease of home-scale AM cultivation. However, when compared to the natural cultivation method outlined above, these commercial products are arguably superior by the fact that the spores in the inoculum have been isolated, identified, cleaned of potential pathogens, and/or tested for their germination rate.

Using the techniques for AM harvesting and identification outlined in Chapter 4, the soil harvested in step 2 of the home-scale AM production protocol can be screened to quantify the species concentration in the collected samples. Though the casual cultivator can simply use whole soil samples, this practice is quite applicable for some of the ecological regeneration strategies discussed in Chapter 10 or to set a baseline to determine if inoculation strategies are successfully increasing the mycorrhizal spore load in a given area. Soil samples can also be tested for the presence and concentration of mycorrhizal species at various labs, such as Soil Foodweb, Inc. in Corvallis, OR.

Ericoid mycorrhizal fungi are relatively easy to cultivate though they have received rather limited investigation. Hymenoscyphus ericae is one of the best-studied ericoid species. Some limited studies have shown that Ericoid fungi can help blueberries and other crops in the Ericaceae grow.[11]

ECM Cultivation	Growth Rate	Culturability	Agar Formula				
			Gamborg	MMN	PDA	Yeast Extract	PACH
Amanita	V/M	A					
Austroboletus	S/M	M					
Boetellus	M	M					
Boletus	M/R	A	•	•			•
Castoreum	M	M					
Chamonixia	M	M					
Cortinarius	S	D					
Descalea	V	D		•			•
Descomyces	S	D					
Elaphomyces	M/R	M					
Gautieria	S	D					
Hebeloma	R	A		•	•		•
Hydnangium	S	D		•	•		•
Hysterangium	M	M		•	•		•
Labyrinthomyces	S/M	M			•		
Laccaria	S/M	D	•	•			•
Lactarius	S	D				•	•
Leccinum	S	D					
Malajczukia	M						
Mesophellia	M	M					
Paxillus	S	D					
Phyiloporus	V	V					
Pisolithus	M/R	A		•			•
Pseudohysterangium	V	V					
Rhizopogon				•			•
Ramaria	M	V					
Russula	S	D					
Scleroderma	M	A		•			•
Setchelliogaster	S	M					
Strobilomyces	S	D					
Suillus	S	D		•			•
Thaxterogoster	M	M					
Thelephora	M						
Timgrovea	S	M					
Tricholoma	S	M			•	•	
Tylopilus	M	V					
Zelleromyces	S	D					

A – Amenable
M – Moderate
D – Difficult
V – Variable
S – Slow
R – Rapid

Cultivating Truffles

Considering the high retail value and potent flavor of gourmet truffles, cultivators in Europe have worked for decades to determine the best cultivation protocol for these fungi. Despite years of research, however, successful harvests are still infrequent. This is largely due to the habitat specificity of a given species. The habitat of Périgord truffles (*Tuber melanosporum*) can be closely recreated in parts of Europe. But only a small degree of success has been achieved with cultivating Oregon white truffles (*Tuber oregonense*) in the United States. Oregon white truffles have reportedly been grown in association with Douglas-fir trees at Christmas tree farms, with some of these truffières producing 300–1,000 pounds (136–453 kg) of Oregon truffles per acre. In general, the habitat requirements of truffles include the following:

- A relatively open tree canopy.
- A soil pH of at least 7.5 and ideally 7.9.
- Soil that is about 40 centimeters deep above fissured limestone, which assists in drainage.
- Protection from winds.
- A slope of less than 5°, which prevents erosion.
- Rainfall and temperature extremes that match the native habitat of the species. *T. melanosporum* prefers cooler NW slopes that are protected from dry southern winds.

Trees are inoculated using the techniques described for ECM fungi. For French truffles, inoculated hazel trees can produce truffles in as short as 3–4 years, while oaks can take up to 7–10 years. This is a trade off, however, as oaks tend to outlive hazels. Trees are often planted at a rate of 100-500 per hectare. Long-term yields depend on the number of trees planted per hectare, the host plant species, irrigation system design, and the skill of the hunting dog and handler. In arid environments, desert truffles from the genus *Terfezia* are often used to inoculate plants from *Helianthemum* (e.g. *Helianthemum almeriense*) with great success.

This washing will reduce the availability of nutrients that can attract pathogens, but is not generally required.

The mycelium can also be washed and then blended for 10–60 seconds in sterile distilled water to create a homogenized slurry that can be applied directly to roots or, better yet, encapsulated in beads of sodium alginate (a seaweed-derived food additive) to enhance the shelf-life of the inoculum and its efficacy at application. The following is a simple protocol for creating these sodium alginate beads:

1. Create a 2% sodium alginate solution in sterile distilled water (e.g. 2 grams per 98 milliliters water). An immersion blender will help create a uniform mixture.
2. Combine this mixture in equal parts with the mycelial slurry.
3. Create a 0.7 M solution of calcium chloride (7.8 grams of $CaCl_2$ per 100 milliliters of water).
4. Drop 4 parts of the sodium alginate/mycelium mixture into 5 parts of the calcium chloride solution. Beads should begin to form immediately and will continue to cure over the next 45 minutes at room temperature. These beads can then be applied directly or stored in water at 39°F (4°C) for up to seven months.

Compost Tea Amendment

Based on limited research, it is becoming increasingly clear that the addition of mycorrrhizal helper bacteria (MHB) is the missing requirement for human-guided ECM establishment.[7] The addition of bacteria, especially fluorescent pseudomonads, has been shown to increase the formation of *Rhizopogon luteolus/Pinus radiate* ECM. Likewise, bacteria isolated from *Laccaria bicolor* fruit bodies have been shown to significantly enhance their ECM formation with Douglas-fir tress.[8] In tropical ecosystems, the bacteria obtained from termite mound powder have been shown to enhance ECM and AM formation with soapbush wattle (*Acacia holosericea*), significantly decreasing the amount of ECM and AM inoculum required.[9] Though more research is needed, I imagine the application of compost tea made from the soil near established mycorrhizal roots systems will help cultivators and silviculturists unlock the potential to cultivate a much wider variety of mycorrhizal species than is currently possible. Indeed, the importance of fungal-bacterial interactions are increasingly regarded as critical intersections to enhancing a wide variety of human practices.[10]

Trichoderma Compost Activator and Plant Supporter

The intentional cultivation of *Trichoderma* species is an additional skill that mycohomesteaders and plant growers can adopt to increase their production of plant-based food. This may seem surprising to many mushroom cultivators, who tend to regard *Trichoderma* species as major competitors in the mushroom farm. However, these globally distributed soil fungi have a wide metabolic capacity which, when cultivated and applied far from mushrooms, offers several major benefits to plant growers.

With its high production of cellulases, *Trichoderma harzianum* can be added to compost piles to increase the decomposition rates of non-woody plant matter. The powerful antifungal properties of *Trichoderma* species also offer the replacement of industrial fungicides by acting as a natural biocontrol for blights and other infections. Different species and strains of *Trichoderma* have been found to reduce the presence of nearly all of the major fungal plant pathogens. These include:

- *Alternaria spp.*
- *Colletotrichum spp.*
- *Crinipellis spp.*
- *Phoma spp.*
- *Pythium spp.*
- *Fusarium oxysporum*
- *F. roseum*
- *F. solani*
- *Helminthosporium*
- *Aspergillus niger*
- *Botrytis cinerea*
- Seedling blight (*Pythium spp.*)
- *Phytophthora colocaciae* and other *Phytophthora* species
- Root rot (*Pellicularis filamentosa*)
- Collar rot (*Pellicularia rolfsii*)
- Dry rot (*Macrophomina phaseoli*)
- Charcoal rot (*Macrophomina phaseoli*)
- Loose smut (*Ustilago segetum*)
- Karnal bunt diseases (*Tilletia indica*)
- Black scurf (*Rhizoctonia solani*)
- Foot rots of pepper and betel vine
- Silver leaf on plum, peach, and nectarine
- Dutch elm disease (*Ophiostoma spp.*)
- Sclerotium forming pathogens such as *Sclerotinia* and *Sclerotium spp.*
- *Verticillium spp.*

In addition to protecting plants from disease, many studies have shown *T. harzianum* to also increase seed germination rates, increase shoot and root length, solubilize phosphates, influence nitrogen fixing, and enhance overall crop quality and yield. However, as many of these studies were conducted under artificial conditions and without the support of mycorrhizal fungi, I have to won-

Apart from Trichoderma *species, various other fungi have been proposed as natural fungicides. The Chytrid* Synchytrium solstitiale *is being considered as a control agent of the plant* Centaurea solstitialis *in the United States.*

der if the benefits of *Trichoderma* species are only found in the absence of beneficial mycorrhizae. The arbuscular mycorrhizal fungus *Glomus intraradices* can cause harmful effects in *T. harzianum*, suggesting a sort of "superiority." Conversely, *Trichoderma* species have also been found to become endophytic in plant roots and aerial tissue; forming a *pseudomycorrhizae*.[12] *T. harzianum* and *T. viride* are some of the most studied species in regard to plant support.

Found in soils around the world, *Trichoderma* species are quite prevalent and easy to cultivate. One method for growing *T. harzianum* is to first isolate the fungus by placing soil samples onto petri dishes containing Richard's Medium. Once isolated, the mycelium is expanded to a liquid inoculum for the creation of grain spawn that is ultimately applied to a final substrate such as sugarcane bagasse, wheat bran, or talc powder. Once the substrate is myceliated, it is added directly to a compost pile or dried and stored for later use. For application, a couple handfuls of inoculum can be sprinkled onto each layer of a compost pile as it is being built. For plant support, the following protocols are suggested:

- **Seeds:** Mix 6–10 grams of *Trichoderma* powder with every kilogram of seed before sowing.
- **Root dip:** Mix 10 grams of *Trichoderma* powder per liter of water and dip cuttings and seedlings in the mix for ten minutes before planting.
- **Established plants:** Mix 10 grams of *Trichoderma* powder into a liter of water. Use this as a drench for the soil near plant stems.

Though *Trichoderma* inoculum seems to be beneficial for nearly every major plant crop, it is recommended to research the impacts that these fungi are known to have on the specific plant you will be working with prior to mass application. *Trichoderma* inoculum is compatible with organic manure as well as *Rhizobium, Azospirillum, Phosphobacteria,* and *Bacillus subtilis* biofertilizers. In many ways, this incredibly beneficial and yet maligned fungus exemplifies the reach of misunderstanding that the Fungal Queendom suffers under, even from some of its most devout allies.

Working With Endophytic Fungi

Considering the various attributes that endophytic fungi provide plants (as discussed in Chapter 2), researchers have begun to investigate the effects of intentionally inoculating plants with the spores of select endophytic fungal species. While the potential benefits of this research are quite compelling (e.g. increased drought and disease resistance in the plant), it is currently unknown how these artificial inoculations will impact the survival of a given plant species in the long term. Many studies on endophytic fungi tend to focus on the isolated effects of individual species, giving little assessment of the combined effects of the numerous endophytes that inhabit a single wild plant. Without an understanding of the overlapping and likely synergistic effects of these numerous fungi, it is difficult to imagine a sound practice for applying endophytes in plant propagation strategies that can ensure the maintenance of what may be site- or plant-specific assemblages of indigenous endophytic communities.

Further, as the populations of these communities are a product of the shifting demands of the environment and the life history of the host plant, a generic protocol for endophyte inoculation may prove detrimental to plants grown under conditions that differ from those for which they were designed. If aggressive endophytes are intentionally inoculated into plants, their habits may outcompete other beneficial species, drastically affecting the health of the fungus-plant and perhaps even changing the evolutionary path of these species. As one study concluded:

> *"Given the ever changing and diverse pathogen assemblages... endophyte-mediated defense is likely to be enhanced when endophytes are highly diverse within and among leaves, plants, and host species."* [13]

A Patagonian endophyte, Gliocladium roseum, *produces volatile hydrocarbons similar to diesel as a byproduct of breaking down cellulose.*[15]

I doubt standardized practices could adequately meet this demand. Techniques for the mass inoculation of plants with endophytic fungi should be thoroughly evaluated for the wide range of impacts that they may have on ecosystem development and future adaptations of indigenous

organisms. And even then, it is likely that our limited understanding of fungal dynamics can fully account for future demands, let alone how artificial endophyte communities will respond to them. Endophytic fungi may offer assistance in the design of regenerative living system of the future, but we must tread cautiously into this unexplored area of research.

If you are interested in researching the effects of endophytes on plants, you will need to isolate some species from a piece of plant tissue. First, the tissue is surface sterilized by being immersed in ethanol for ten seconds and then briefly passed over a flame. The tissue is then opened up and segments are placed in a sterile petri dish under aseptic conditions. Many agar formulas can be used, though PDA is a common choice. After several days, weeks, or months of incubation, mycelium will begin to emerge from the plant tissue and grow across the agar. As more and more species begin to appear, a tapestry of co-habitating species arises across the plate. From here, each species is then subcultured, isolated, and amplified using methods similar to *Trichoderma harzianum* cultivation. If spores are obtained from the endophyte, they can be diluted in sterile water. This mixture is then sprayed directly onto plant leaves or used to soak seeds that have been surface sterilized by submersion in 70% alcohol.

To inoculate plant roots with dark septate endophytes (DSEs), two-day old plant seedlings can be placed into agar plates containing a DSE growing on Oatmeal Medium. After incubation for several weeks at 73°F (23°C) under a lighting cycle of 18-hour on/6-hour off (at 600 lux), the association will ideally form.[14] *Piriformospora indica* is an endophyte that acts like AM fungi, but is easily cultivated without a plant associate.

Mycodynamics: The Sidereal Timing and Bioenergetics of Mushroom Cultivation

In June of 1924 a new paradigm for the cultivation of crops and fertile lands was proposed in Germany by the author and philosopher Rudolph Steiner. As a response to growing concerns around the recent invention of chemical fertilizers, Steiner gave a series of talks to a group of farmers in which he described a method for growing food that was free of chemicals. These classic talks are considered today to be the first description of what is now called organic farming. But beyond just eliminating the chemicals of concern, Steiner also advocated for farmers to integrate various natural forces and unique amendments into their practices. This system later became known as biodynamic farming.

A unique and central aspect of the biodynamic system is the use of nine preparations ("preps") that, at first glance, may seem unusual. With recipes that include diluted quartz crystal paste and buried animal parts, biodynamic preps do not fit into the modern definition of fertilizers. This is because preps are not fertilizers in the traditional sense, but materials designed to draw in formative, etheric forces that help enhance the life of a landscape and the inherent abilities of the organisms it contains. Akin to homeopathic treatments, biodynamic preps are heavily diluted in charged water, which serves as a carrier of the ingredients' energetic signature.

Though quite radical for its time, the philosophical basis of Steiner's system was not without forms of precedent. Much of biodynamics can be seen as an outgrowth of the sidereal astrology described by Ptolemy and various aspects of Zoroastrianism. It is also reflective of the doctrine of signatures discussed in Chapter 7. However, as opposed to attributing elemental and astrological relationships to whole plants, biodynamics focuses on the correspondences between the elements and the individual parts of an organism. For mushrooms, mycelium is related to the Earth (and Earth signs), the fruit body to Water (and Water signs), and the spores to Air and Fire (and Air and Fire signs). It is from these relationships that the second major aspect of the biodynamics arises: the administration of various farming tasks in relation to the position of the Moon and Zodiac.

In the decades since Steiner proposed the biodynamic system, a variety of farms and organizations have worked to test the effects of its preps and practices. While results and opinions have varied over time, a majority of the research has demonstrated an increase in productivity in biodynamic crops when compared to control groups. Today, biodynamic certification is increasingly sought by consumers of food products, as artificial chemicals are essentially absent from all biodynamic

Steiner delivered more than 6,000 lectures on at least 350 different subjects. A true polymath, Steiner is respected for his insights into education, medicine, philosophy, science, art, drama, literature, architecture, and agriculture, many of which hold great influence today.

practices, placing them in many ways "beyond organic." For mushroom growers, this means that work surfaces can only be cleaned with hot water. These high standards not only support the health of the consumer of biodynamic food, they also help increase the resiliency of the farmer by making every farm a low-input, self-sustaining organism—a network of nutrient distribution that flows between animal, plant, and farmer. Biodynamic farming has become especially popular in many vineyards in Oregon and California, which claim that biodynamic grapes produce superior wine.

For all of this history, very few guidelines have been developed over the decades for biodynamic mushroom cultivation, potentially due to Steiner's unfortunately outspoken disregard for fungi. Currently, the only biodynamic mushroom farm in the U.S. is Tumbling Creek Farm, a Shiitake, Oyster, and Lion's Mane producer located in Nevada City, CA.[16] With such a small amount of data to grow on, I present here the basic concepts of biodynamics in regard to mushroom cultivation in hopes of inspiring more research into this important field.

The Preps

Vortexed Water

Long before the work of Dr. Masaru Emoto demonstrated the effects of thoughts and words on the structure of water,[17] the pioneering work of Viktor Schauberger and later Rudolph Steiner argued that water is Nature's primary carrier of information and intention. As a central aspect of biodynamics, Steiner strongly encouraged farmers to irrigate their land with water that had been charged with one's positive intentions. This charged (or dynamized) water is created with strong, alternating vortices. A bucket is filled three-quarters full with high quality water and then stirred in one direction with a wooden stick or rod. Once a strong vortex is achieved, the direction is reversed. This back-and-forth stirring is then continued for an hour, during which time the water is oxygenated, purified, and enlivened. Some practitioners sing while they stir, going up the scale while spinning anti-clockwise, and down the scale in sync with clockwise motions. Good intentions are held throughout as the water will draw in these thoughtforms in tow with many other potential and kinetic life forces. As human interaction is central to this process, electrical equipment cannot be used to vortex water. After about 30 minutes the water usually begins to feel more slippery and easier to stir, a signal that the water is taking on new properties. Once the vortexing is complete, the water is then sprayed or flicked across crops or land to bring its message to the plants, microbes, and fungi of the substrate or field.

Field Sprays

These preps are applied directly to installations and the surrounding landscapes to raise the energetics of the area.

- **500:** Fill the horn of a cow that has birthed a calf with fresh cow manure in the autumn and then bury it in a fertile field until spring. Dig up the horn and store the contents in a glass or ceramic vessel that has a loose lid, is set in peat moss or soil, and is placed away from any chemicals. For application, mix 35 grams in 13 liters of water and vortex for one hour and apply to substrates during mixing. 500 stores for up to two years.
- **501:** In the spring, fill a cow horn with a paste made from finely ground quartz crystals and rainwater. Bury the horn, then retrieve it in the autumn. For application, mix 1 gram in 13 liter of water and vortex for one hour. Place the mix in the light of the full Moon overnight and apply in the early morning of sunny days when fruiting begins to encourage growth and strengthen the effects of light and warmth.
- **508:** Harvest horse tail (*Equisetum arvense*) plants in the spring, dry them, then soak them in water for two weeks. Filter the mix and add 1.25 cups (0.3 L) of the liquid portion to 2 gallons (7.5 L) of water and vortex for 30 minutes. Spray onto substrates during the full and new Moon.

All matter originates, and exists, solely by virtue of a force which induces particles to vibrate.
—Max Planck

Compost Additives

These six preps are added directly to compost piles to draw in formative forces and enhance the growth of composting microbes.

- **502:** Yarrow (*Achillea millefolium*) flowers are harvested and dried in the autumn. In the spring, these flowers are stuffed in an inflated and dried deer buck bladder. The bladder is stitched closed and hung from a tree facing the Sun. The following autumn, the bladder is buried in the ground inside an earthen container. The following spring, the flowers are retrieved. 502 helps spirits penetrate matter, enabling it to attract trace minerals. It is important for reproduction and growth. 502 is associated with Venus.
- **503:** Chamomile flowers are harvested in the morning, stuffed in a bovine intestine, and buried in the soil during autumn inside of an unglazed earthen jar. 503 helps assimilate calcium and stabilizes nitrogen within the compost, increasing soil life and helping stimulate growth. 503 is associated with Mercury.
- **504:** Whole stinging nettle (*Urtica dioica*) plants are harvested in the late spring or early summer, dried, then buried in the autumn in an open earthenware container or inside of peat moss. Twelve months later, the material is harvested and sieved to remove any stalk pieces. 504 enlivens the soil and improves nutritive qualities. It is associated with Mars.
- **505:** European oak (*Quercus robur*) bark is grated to a powder and buried inside of a clean cow or sheep skull in the autumn in a swampy area. Retrieve the material in the spring and place it in a glass container. 505 activates Moon forces and restores balance.
- **506:** Dandelion (*Taraxacum officinale*) flowers are harvested on a summer morning, dried, stuffed inside of a dried mesentery of a cow, and buried in the autumn in an unglazed earthen jar. In the spring the material is retrieved and placed in a container with a loose lid for several weeks. 506 is associated with Jupiter.
- **507:** Valerian (*Valeriana officinalis*) flowers are harvested in the spring when the Moon is in Libra or Gemini from plants that were planted a year earlier. The flowers are ground thoroughly and mixed with four times their volume in distilled water in a glass jar. The jar is placed on a sunny windowsill for seven days. Finally, the material is filtered and the liquid stored in a sealed container. Mix 10–15 drops into 7 gallons (26.5 L) of water and stir for ten minutes. 507 is associated with Saturn.

Adding Biodynamic Preps to Compost

For plant compost, preps 502–507 are traditionally added to a hot compost pile as soon as it is built. Five 50-centimeter-deep holes are first made in a circle around the pile with a stick and an additional hole is made in its center. Preps 502–506 are then placed into separate balls of cow manure, each ball containing 0.10 teaspoons of prep per cubic meter of compost. These balls are then inserted into each of the holes individually (one ball per hole). Half of the 507 mix is poured in the center hole and the rest is poured over the whole pile.

Compost for mushrooms may require a slight alteration to this formula. A document I obtained from the Soil and Health Library[18] on biodynamic mushroom compost preparations suggests diluting prep 500 at a rate of one portion to 6 gallons (23 L) and spraying this on the compost pile as it is built. Once built, insert preps 502–507 in half their normal quantities, then spray the whole pile with 507 at a rate of one portion to 2 gallons (7.5 L) of water. Feel free to experiment. I am particularly curious as to the effect of these preps on inoculated compost-based substrates. At Tumbling Creek, these preps are added to their spent spawn piles. Several weeks later, massive mushrooms pop out, some as large as 6–8 inches (15–20 cm) in diameter!

Biodynamic Timing

In biodynamics, the timing of when to commence inoculations, spawning, and harvests is guided by the rhythms of celestial bodies. The location and phases of the Moon are observed closely as their influence on the flow of water within a mushroom directly influences the growth and ultimate yields of a crop. Mushrooms intended for cloning should be harvested with the Moon ascending so as to capture the rising water and forces being drawn into the fruit body. Conversely, spawning is best done during the descending Moon, which helps draw forces down into the mycelium, supporting its establishment and longevity.

If possible, harvests should be timed to occur around the full Moon. In the days leading up to the full Moon, spore germinations can occur more rapidly and fruitings may arise prematurely. I have seen this repeatedly with Lion's Mane mushrooms, which can fruit prior to full myceliation of a substrate on the days surrounding the full Moon. Such self-determined fruitings are also noticed at Tumbling Creek, which sells some of these larger crops to the local pizza parlor for their monthly "Full Moon Pizza" special. This lunar influence is even more pronounced when the full Moon is at perigee, its closest position to the Earth.

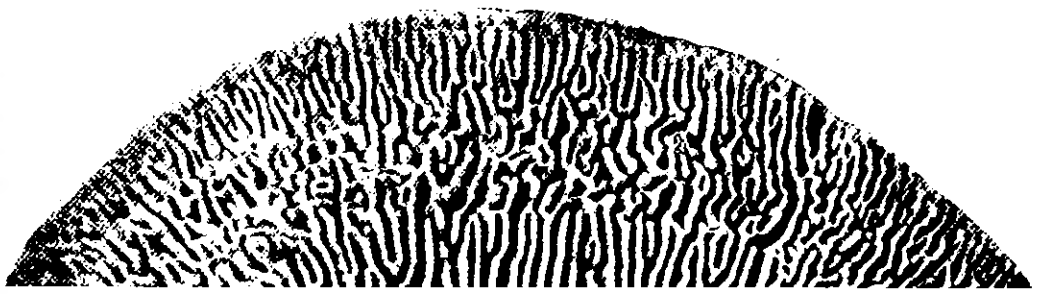
The sidereal positioning of the Moon also seems to influence the yields of mushrooms. One study found that, upon correlating the inoculation dates of Shiitake blocks with the position of the Moon, the greatest yields were obtained when spawning occurred on days that the Moon was in a Fire or Air sign. Further, the most significant inoculation days were Good Air days, which produced the greatest yields, and Bad Earth days, which led to the lowest yields.[19] These days are set by the Magi Society. As noted in the section on spagyrics in Chapter 7, the astrological correspondences of mushrooms are not well defined. Suggested inoculation dates may vary by species.

- **Moon in Aries:** Barren and dry. Good for dealing with pests and contaminants. Not good for spawning.
- **Moon in Taurus:** Moist and productive. An Earth sign, good for spawning outdoor installations.
- **Moon in Gemini:** Same as for Aries.
- **Moon in Cancer:** Moist and fruitful. The best sign for spawning.
- **Moon in Leo:** The most barren and dry of all signs. The worst for spawning.
- **Moon in Virgo:** Barren. Not good for spawning.
- **Moon in Libra:** Somewhat moist and semi-fruitful.
- **Moon in Scorpio:** Very fruitful and moist.
- **Moon in Sagittarius:** Barren and dry.
- **Moon in Capricorn:** Fruitful, somewhat moist. Earth. Good for spawning.
- **Moon in Aquarius:** Barren. Good for dealing with pests.
- **Moon in Pisces:** Very fruitful and moist. Very good for spawning and dunking.

Other Helpful Design Elements

With the core skills of natural mushroom cultivation covered, this final section explores several additional practices that can significantly enhance the overall resilience and regenerative capacity of any mushroom cultivation design.

The following equation approximates the amount of rainfall that can potentially be harvested from a rooftop:
Total square footage X Annual rainfall (inches) X 0.623 = Rainwater (gallons)

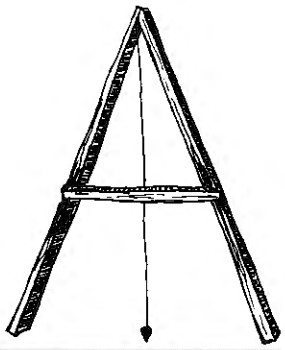


Rainwater Harvesting

If an outdoor installation dries out, its growth rate and overall yield can decrease significantly. As such, ensuring that a fresh supply of high quality water is constantly available for any installation should be a primary consideration. Collecting rainwater and channeling it to an installation is arguably the most cost-effective and resource-conscious means for providing water to fungi.

Rainbarrels

A simple method for collecting rainwater is to direct the downspouts of rooftop gutters into holding barrels or cisterns. For areas that receive a large amount of rainfall, a series of cisterns or other large containers can be chained together to create a large water-holding reservoir. How many collection tanks are installed depends on the amount of rainfall to be expected over the course of the year as well as the space and budget constraints of the project. Many rain barrel designs can be found online.[20] Always plan for the event of heavy rains that can cause a system to overflow.

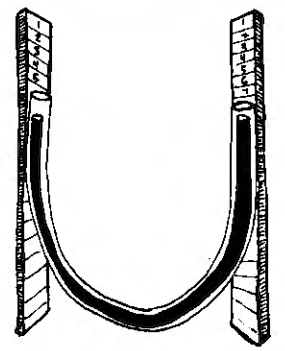


A-frame.

Swales

Swales are ditches that are designed to capture water rushing across a sloped area during rain events. Swales are often dug "on contour," meaning they follow the same elevation across a slope and are perpendicular to the vertical axis. By digging a swale on a consistent elevation, the water that fills the swale during a rain event is unable to move downhill. Instead, the water is held in place where it can slowly spread and sink into the ground, providing a rich reserve of water in the soil downhill from the swale. The first step in designing a swale is to map the contour of the land. There are two simple ways to accomplish this:

- **A-Frame:** A large A-shaped frame is used to suspend a heavy object, such as a bolt from a piece of string which is then "calibrated" to find the center of the cross beam. The frame is then slowly walked across the land. At each "step" the frame is adjusted until the string falls at the center mark and a stake is placed in the ground at the frame's foot. After the frame has been walked across the slope, the resulting string of markers will signify a constant elevation.
- **Bunyip:** A 5–10-meter length of transparent hosing is attached on either end to meter sticks. It is best if the numbers at the top of the stick start at 1 and count up as the numbers go down the stick. Food coloring is added to the water that then fills the hose and the hose is then stretched across a piece of land. As one stick is held in place, the other is moved until the reading on both measuring sticks is the same, signifying that both sticks are at an equal elevation.

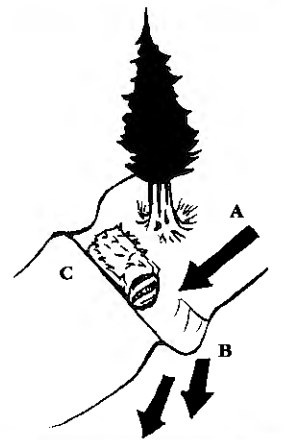


Bunyip.

Once a contour is mapped, the swale can be dug shallow or deep depending on the amount of water to be harvested. The dirt removed to make the swale should then be built up on the downhill side of the swale, forming a berm. To prevent the berm from blowing out, it should be built four times wider than it is tall with a 1:2 slope. A series of swales and berms can be staggered down a hillside to help hydrate the land evenly.

Keyline Ponds and Elevated Dams

In the event of a very heavy rainfall overflow, swales should also be designed with an overflow system to avoid the risk of the berm or other features being washed out. These overflow courses can be channeled to sewer systems or flood plains. Or, if space allows, a pond can be constructed to collect and hold this excess water for years. Overflow channels should be positioned at least 4 inches (10 cm) from the bottom of the swale and at least 4 inches below the top of the berm. Large dams can also be constructed on contour to act as a very large swale.



(A) Water rushes down flat hillsides unimpeded. (B) If a swale is dug, the water will be held for an extended period, allowing it to sink and spread into the ground. (C) If a mushroom bed is placed in that water way, a function is added to the system.

The alteration of the physio-chemical properties of soils by biochar have been shown to reduce soil methane emissions, nitrous oxide emissions, the need for input of fertilizer, and the leaching of nutrients, while simultaneously increasing plant growth, soil pH and CEC, soil aggregation due to the increased presence of AM fungi, levels of available Ca, Mg, P, and K, soil microbial respiration, soil microbial biomass, and nitrogen fixation in legumes.

Biochar

When organic material is cooked in a high-heat and low-oxygen environment, a process known as *pyrolysis* will occur in which the material's non-carbon atoms volatize as gases. If these elements are fully expelled, the carbon will be left behind in a highly stable (recalcitrant), crystalline form known as *biochar*.

In recent years, biochar has received significant attention in soil studies as it has been found to produce a surprisingly wide variety of benefits to plant health. Many of these benefits seem to be attributable to the slight electrical charge and high surface area to volume ratio of the material, both of which cause biochar to adsorb and retain a large amount of water and nutrients. Further, biochar also seems to be a preferred habitat for microbes and fungal hyphae, which are commonly found to inhabit biochar's recesses.

A number of methods have been designed for producing biochar. Most producers utilize specially designed stoves that can be made by modifying coffee cans, trashcans, 55-gallon steel drums, or even larger metal containers. Larger designs and further information on this burgeoning field of research can be found through the organizations Biochar International and SeaChar.[21]

"...[M]an's most useful ally in his struggle for survival, considered by Darwin the greatest plowman, an animal of greater value than the horse, relatively more powerful than the African elephant, and more important to man than even the cow."[22]

The incredibly high number of beneficial microbes produced in worm castings play a key role in the health of an intact soil ecosystem. Worms were held sacred by the ancient Egyptians and have been argued to lie at the foundation of civilization itself. Worm castings are five times as rich in available nitrogen, seven times in available phosphates, and 11 times in available potash as anything in the upper 6 inches of soil.[23]

Vermiculture

Red wriggler worms are an excellent addition to any urban or rural mushroom growing practice. Easy to manage, worms produce a nutrient-rich substrate (castings) that can be used by cultivators in substrate formulas or compost teas. Their presence can also support the success of mycorrhizal cultivation or remediation strategies by churning and aerating soils. Many vermiculturalists raise their worms on kitchen scraps and newspaper. However, worms also consume, and even seem to prefer, protein-rich spent spawn, making them a multi-functional loop-closer for turning this mushroom "waste" into an amendment for growing more mushrooms.

Worms are often raised in a large wooden box or plastic tub that has been modified to allow for moderate airflow and drainage. Bins are typically started with a 3–4-inch (7.5–10 cm) layer of moist newspaper strips, a small amount of kitchen scraps, and a small handful of worms, often available from horticulture supply houses. Once established, worms reproduce rapidly and can eat about half their weight in food each day. Worms should be fed fruit and vegetable scraps, grain products, coffee grounds and filters, and tea bags. They do not like meat, fish, oily foods, dairy products, or pet wastes.

Worm bins often incorporate three stacked containers. The bottom container collects the "tea" produced by the system (a good plant fertilizer), while the middle container is where the worms reside. As the middle layer runs out of food, new food is added to the top bin, encouraging the worms to travel upward. The middle bin is then swapped with the top bin and the castings are harvested.

Actively Aerated Compost Tea

The production of aerated compost tea is a simple method for creating a liquid inoculum of beneficial, oxygen-loving microbes and microfungi. This tea has a number of applications in fungal cultivation, two of the most relevant being the inoculation of hot compost piles to speed up their decomposition and in remediation installations where a diverse soil flora can assist in chemical degradation and support plant health. Soils dominated by aerobic microbes are considered ideal for most plants as their byproducts are not harmful, unlike the formaldehyde, volatile acids, and phenols produced by anaerobic microbes. A variety of recipes exist for making compost tea but, for the purposes of *Radical Mycology*, some worm castings and other nutrients are all that are needed. The following recipe is recommended by soil expert Dr. Elaine Ingham and comes from the book *Earth Repair* by Leila Darwish:

1. Fill a clean 5-gallon bucket with high quality water.
2. In a nylon stocking or specialty compost tea bag, mix 1 cup worm castings or finished and fresh hot compost, 0.25 cups (60 mL) mix of 1:1:1 unsulphured molasses:fish hydrolase:kelp, and 1 tablespoon of humic acid.
3. Place the stocking in the water and actively oxygenate the liquid for 24–36 hours at 55–80°F (13–27°C).
4. Once finished, filter the solids out of the tea. The liquid can then be applied by directly pouring onto soils or spraying onto foliage. Compost tea must be used within 4 hours as the aerobic microbes will quickly die if left in non-aerated water.

The most important aspect of the compost tea brewing process is that a strong aerator is used to ensure that the water is being infused with the high levels of dissolved oxygen that these microbes require. DIY bubbler builds can be found online but most are not strong enough to produce a good brew. Shop around.

Biogas / Methane Digesters

When anaerobic microbes ferment organic wastes, methane gas is released as a byproduct. If collected, this gas can be used as a fuel source for warming buildings or cooking substrates. Methane digesters are increasingly common in countries around the world. Many rural Chinese families utilize $80 methane digesters to provide around 60% of their home's fuel needs. Often these digesters are fed waste products, with animal manures tending to produce the greatest methane output.

Several studies have also demonstrated that spent mushroom spawn, with its abundance of sugars, can also serve as a good nutrient source for biogas systems. *Pleurotus* spawn in particular seem to produce a high amount of biogas.[24] The leftover, odor-free residue can then be incorporated into soils as a fertilizing amendment, used to nurse plant seedlings, or fed to pigs. The substrate tumbler described in Chapter 8 can be equipped with a modified lid to act as a biogas digester.

Forces from the Mycosmos

Following on the principles of biodynamics, a variety of alternative practices can be initiated to help draw formative energies into a mushroom growing operation. Obelisks or the orgone generators of researcher Wilhelm Reich[25] are said to increase the vitality of landscapes and even rainfall. One practice with a surprising amount of modern anecdotal support is the production of food inside of pyramid-shaped structures built with the same proportions as the Giza Pyramid. Pyramid-shaped greenhouses and objects have been reported to increase seed germination rates and overall plant growth, and to help preserve food.[26]

The ultimate goal of farming is not the growing of crops, but the cultivation and perfection of human beings.
—Masanobu Fukuoka[27]

Integrating the Elements: Weaving the Web Tighter

Having digested the skills presented in the last chapter and in the sections above, cross connections can now be formed between the many branches in the growing knowledge web. The resiliency that can be gained through natural mushroom cultivation is not found in a rigid adherence to protocols. Rather, it is through embodying mycelial patterns of connectivity that cultivators find the best means to reduce energy inputs and increase self-sufficiency. When installations and living systems are integrated to the point that they are able to sustain themselves—when they are regenerative—that is when the path toward greater self-reliance and autonomy begins to fully open.

Just as fungi must adapt to dynamic environments, so too must cultivators account for the demands of the world that constantly influence our lives. Mushroom cultivators do not just grow mushrooms. We also eat, sleep, and spend time with those we hold dear. By creating living systems that are intelligently designed, well connected, and regenerative, mushroom cultivators can reduce the stress and costs of their work, creating more space to think, create, and be. Integrating the elements leads to more prosperous natural mushroom cultivation and, ultimately, toward a more refined approached to living. Presented below are just a few of the many ways that fungal installations can combine the elements listed throughout this chapter.

Water Wise Fungi

Wherever water exists in abundance, fungi follow. The water catchment systems described earlier are several means for collecting water, but how should that water reach installations in a way that is most efficient? For rainbarrels, the options are fairly straightforward: lead the water from the point of collection to the site of myceliation. If the rain barrel is situated at a higher elevation than the installation, gravity can do the work required to bring this water downhill, replacing the need for pumps. This water can be trickled over the bed via drip lines or channeled to run through perforated pipes inside of the bed. Alternately, clay pots can be placed throughout a chip bed or compost row and filled with water that will be slowly released through the porous structure of the pot. Where rain catchment systems are limited in capacity, overflow pipes can be directed to a series of inoculated French drains to distribute this excess water across a garden or perhaps through a web of drains, reflective of a mycelial network.

For swales, I suggest securing mushroom beds at, or just below, the high water mark on the north facing aspect of the swale. In the rainy season, these mushroom beds will be occasionally submerged in an excess of water as the swale rapidly fills with water. A day or two later, this water will have sunk into the subsurface soil, leaving the mushroom bed thoroughly hydrated. This way, the bed will stay wetter during the drier months while the year-round shade of the slope will reduce desiccation and keep temperatures moderate. An added benefit of this fungal function is that the mushroom mycelium may help reduce erosion by helping adhere soil particles and debris into a contiguous and stable matrix.

Grey Water Filtration

Another viable source of water for hydrating mushroom beds is the grey water produced by kitchen and bathroom sinks and from washing clothes. The collection and use of grey water is not unheard of among vegetable and fruit growers who have found that this phosphate-, salt-, and oil-rich water can be tolerated by a range of trees and shrubs. Though case histories are limited with outdoor mushroom installations, I have had great success using grey water to hydrate beds inoculated with King Stropharia and Phoenix Oysters, two species that are particularly tolerable of funky substrates.

Grey water systems come in a variety of forms. A common and simple system is to collect it in buckets under sinks to distribute outdoors. More elaborate systems include retrofitting the plumbing systems of sinks or clothes washers to channel grey water directly into a garden. Ideally, only biodegradable and salt-free soaps are used.

A curved "raft" style bed being installed at the Food Cooperative in Olympia, Washington. Dug on a slope, this mini-swale will hold and slowly release water for the apple tree roots below.

Stacking Functions: Mushrooms on Compost

The heat produced by an aerated compost pile can be utilized to warm a mushroom bed and increase its growth rate. This idea was first proposed to me by a presenter at the 2014 Radical Mycology Convergence. There, two compost piles were constructed of cow manure and straw and covered with a perforated cardboard buffer. A woodchip and King Stropharia sawdust spawn sandwich was installed on top of the cardboard and insulated with straw.

Over the ensuing weeks, the compost and myceliating substrates were monitored to ensure that proper composting temperatures were achieved, but that the mushroom mycelium was not overheating or drying out. As the mycelium established and the pile began to cool, the fungus began to travel through the cardboard and to infuse itself in the compost below. Once inoculated, the compost was later spread across the land to help build topsoil, channel nutrients and water throughout the environment, and support plant health.

Fungi and Plants

Apart from the numerous benefits of integrating mycorrhizal fungi into plant propagation strategies, the mushroom-forming saprobes also find themselves well suited in a greenhouse or garden. Wood-based mushroom beds can be cited in all of the unused and shadier areas of a greenhouse or garden or they can be applied directly over the plant's soil to act as a living mulch. As a mulch, mushroom beds help suppress weeds, regulate soil temperatures, reduce the need for watering, warm the soil, and expel CO_2 directly into the underside of the plants. As the plants intake this CO_2 through their stomata, they expel O_2, which the fungi capture. With these gasses cycled, the potential exists for closing greenhouses in colder months to help extend the growing season, an intriguing prospect. If Reishi mushrooms are grown in a greenhouse, their spores will cover the leaves of plants, an effect that has been anecdotally shown to eliminate insect infections and diseases.

In a limited number of experiments, several mushrooms have been found to companion well with certain plant species and effectively help increase the size, health, and yield of the plants. When applied over *Brassica* beds at the beginning of a growing season, sawdust inoculated with the Elm Oyster has been shown to increase root ball size, stem length, and overall yield in the plants when compared to uninoculated controls.[28] My friend Pat Rasmussen may have discovered a similar plant-fungal relationship by accident.

During the early months in the 2014 growing season, Pat planted several *Aronia* bushes—a blueberry relative—of the same size and from the same nursery stock in two different edible forest gardens in Olympia, WA. Both plants were placed in healthy soil and equally well maintained throughout the season. The one difference between the two plants was that one was installed amongst a woodchip bed inoculated with the Nameko mushroom. By mid-November, the impact of the mushroom bed on this plant was quite apparent. Not only was the ground covered in a little sea of Nameko mushrooms, the *Aronia* plant that they surrounded had grown 45 inches (114 cm) tall and hosted a hefty berry set. The other plant had only grown to 22 inches (56 cm) in the same season. What makes this discovery more notable is that it was a complete accident. Pat never intended to grow Nameko, she had ordered Elm Oyster spawn for the installation but was sent a mislabeled bag instead. Such is the way that science slowly branches forward.

Despite the exciting potential that the field of plant-fungal relationships offers, the limited amount of research surrounding the topic has left us with only a few well-established companionings to date. These include Reishi and raspberry, King Stropharia and sweet corn, and Pearl Oyster and *Cannabis*. The low number of known relationships is not due to a lack of them, but rather due to a lack of researchers dedicating land plots and spawn to uncovering where these intersections lie.

Considering that the *Brassica* plants noted above are one of the few plant families that do not form mycorrhizal associations, a good starting place for future research would likely be working with other non-mycorrhizal forming plants, such as those in the Chenopodioideae (e.g. Beets, Mustard, Spinach, and Good King Henry). I am especially interested in how the companioning of mushroom species with perennial plants can support the life of these plants over multiple years.

Spent Spawn Plant Hormone

Studies from Japan have shown the following extract to increase the strength, disease resistance, and production of various crops (e.g. cucumber, tomato, eggplant, soybean).

1. Mix 1 kilogram of spent spawn in 5 liters of water.
2. Adjust the pH to 4.5–5.5.
3. Incubate for 4–5 hours at 40 - 50°C in a sealed container.
4. Filter and dilute the liquid fraction 300-500 fold in water.
5. Spray on plant leaves two times per week.

Fungal Functions for Food Forests

Forest gardening is a land management strategy that mimics multi-storied woodland ecologies by densely planting productive trees, shrubs, vines, groundcover plants, and root crops. Known as "edible forest gardens" or "food forests," these dense systems are designed to produce an abundance of food while also acting as a self-supporting ecosystem. Many wonderful books have been written on food forest design.[29] The following are the fungal functions that I suggest all such systems should incorporate to maximize their efficiency:

- **The mycorrhizosphere:** Plants should be inoculated with the mycorrhizal fungi that they are known to associate with (e.g. AM species, ECM species with appropriate trees, ericoid species with Ericaceae plants). Aerated compost tea should also be incorporated to enhance the density of beneficial microbes and soil yeasts in the soil. The many benefits of mycorrhizal fungi are critical for food forest designs where adequate nutrient distribution is essential for the survival of such a high plant density. The health of the soil's ecology is tantamount to the overall success of the entire food forest. Fungi are keystone species in soil processes.
- **The mushroom layer:** Mushroom beds can be incorporated among groundcover plants. Planting groundcover crops on top of mushroom beds may even increase the yields of the mushrooms by providing a high humidity microclimate to developing primordia as well as additional nutrients.
- **The log layer:** The cool, moist microclimate of a food forest understory is an ideal place for incubating mushroom logs. If the conditions are appropriate, the logs may also be fruited here, reducing the need to travel to multiple locations to harvest crops.
- **Mycohügelkultur:** Hügelkultur is the practice of burying woody material within piles of soil to create large raised garden beds. Over the ensuing years, fungi will digest the wood, providing a constant source of water, nutrients, and warmth to plant roots. The intentional inoculation of this woody material with edible and medicinal white rot fungi is a simple method for accelerating this decomposition process. If buried near the soil horizon, mushrooms will arise from these buried logs, adding an additional crop to the food forest. The best hügelkultur mounds are said to be tall and steep. Using inoculated logs to brace these tall beds is another simple method for integrating mycotems into a food forest design. Logs can also be buried under the berms on the downhill side of a swale.

Fungi and Livestock

The nutritional and medicinal qualities of mushrooms and their mycelium do not only benefit humans. A surprisingly large number of studies have demonstrated that many wild and domesticated animal species are supported by these functional foods, providing a natural alternative to the antibiotics that are often used in abundance on livestock. Here are some of the major highlights that have been demonstrated by researchers over the last few decades:

- **Cows:** When grown on poplar shavings, Artist's Conk and Turkey Tail were found to improve ruminant digestibility of this substrate by up to 62%.[30] In Europe and New Guinea, *Phallus impudicus* is given to cattle to encourage reproduction.
- **Chickens:** Witch's Butter has been shown to help chickens with *Eimeria tenella* infection.[31] Shiitake polysaccharide extracts have been demonstrated to help increase chicken growth and the population of beneficial microbes in the chicken ceca. Chickens fed Cordyceps produce eggs with cordycepin, 30% less cholesterol, and a sweeter taste!
- **Lambs:** Spent Oyster wheat straw can be fed to lambs as up to 20% of their diet.
- **Bees:** The smoke from the Birch Polypore, Cramp Balls, and *Calvatia spp.*, can be used to sooth bees during handling. A condensed or vacuum-distilled tea made from the Red Belted Conk can be fed to bees to potentially increase their immune response.

Fungalley Cropping

Alley cropping is a sort of scaled down version of food forests where, instead of a diversity of plant types and heights being encouraged, rows of perennial trees are interspersed with low-lying crops. As the tree crops increase in age and height, the spaces between rows become increasingly shaded out, ultimately limiting the growth of most plants. Sounds like a perfect place to grow mushrooms, no? Shade + Water + Wood = Mushrooms. Always.

Mycelium: The Plastic of the Future, Now

An additional application of working with fungi that compliments any low-input and resource conscious lifestyle is growing mycelium into molds to create artistic or functional objects. Mycelium is like a glacier, slowly flowing through and taking on the shape of its container. For the majority of the history of fungal cultivation, mycelium has been grown into bags or bottles. However, as long as the fungal needs are accounted for, mycelium can be grown into a wide array of shapes, a concept that is limited only by the creativity of the cultivator.

Once grown into a desired shape, mycelium should be removed from its mold and dried to ensure longevity. If left to grow too long, the mycelium may fall prey to competitive molds and microbes. Once dry, however, mycelial objects offer a combined set of physical properties unparalleled by most other building or sculpting media. In general, dried mycelium is lightweight, rot-resistant, buoyant, highly insulating, and extremely fire-retardant. If kept dry, a mycelial object or structure will persist indefinitely. But, if desired, the material can be hydrated and left to decompose in just a matter of weeks. As a densely woven and distributed network, mycelial objects can readily absorb physical impacts and vibrations, giving it a stress tolerance that can surpass bricks and other traditional building materials. These traits are most prevalent in the tenacious mycelium of *Trametes, Pleurotus,* and *Ganoderma* species, with the latter being commonly cultivated for its structural properties.

All combined, these physical properties suggest that mycelium can easily replace nearly any object that is currently made from Styrofoam as well as many materials that are primarily made from wood. Cars, airplanes, trains, boats, batteries, furniture, ashtrays, helmets, shoes, storage containers, buoys, bricks, particleboards, and building insulation can all be built wholly or in part with mycelium-based products. Simple molds for objects can be easily created by using methods found in ceramics molding, while more elaborate or complex molds can be custom designed using computer modeling and thereafter 3-D printed. Myceliated substrates can even be used as the 3-D printing material. The application of mycelium as a modeling material on its own or in concert with the specificity of 3-D printers provides for what I see as an explosion in the not-too-distant future of cottage-scale industries creating valuable objects from mycelium, a biodegradable building material with nearly endless potential.

Taking these principles a step further, the question of whether an entire building could be constructed primarily from mycelium is not uncommon among cultivators. Mycelial bricks and boards can be made to match standard specifications in molds made from plastic, wood, or even dried mycelium. But as the quality of different mycelia and their combination with a given substrate will affect the physical properties of the final object, experimentation is needed to find the best combination of fungus and substrate to match the engineering demands of a given project. The high tensile strength of hemp (*Cannabis spp.*) fiber is an ideal substrate for building high quality mycelial building materials, especially if a combination of small particles and long fibers are used. For any mycelial building project, one of the greatest challenges will be ensuring that the mycelium does not rehydrate and decay after construction.

Beyond these more static objects, research is also underway for cultivating mycelial mats that will function like fabrics and flexible materials. Depending on the species and the cultivation condition, pure mycelial mats can be grown that perform and feel like rubber or leather. Researchers are hoping that within the next decade not only will building materials be made out of mycelium, but many furniture and clothing items as well. As mushroom cultivation becomes increasingly commonplace around the world and increases in accessibility, how resources and goods are developed and distributed through a society will drastically alter to reflect the vast potential offered by the fungi. Along with all of the skills presented in this chapter, I think such a change in how whole societies manage their wastes will be one of the greatest contributions that the current mycocultural revolution will spawn for generations to come.

- **Fish:** Yeasts, dried mushrooms, and their mycelium can be fed to fish to help supplement their diet with a medicinal additive. *Candida utilis* has been shown to be an adequate protein source in feed mixes for tilapia.[32] One study showed that extracts from *Cordyceps sinensis* improved the growth performance and health of

pacific white shrimp.[33] Another showed that the addition of 10–20% of *Penicillium* mycelium to fish feed increased the growth of glass eels while reducing their nitrogen excretion.[34] The addition of 1–2% of Chaga extracts to the diet of kelp grouper (*Epinephelus bruneus)* increased the immune response in the fish, ultimately decreasing mortality rates from *Vibrio harveyi.*[35] Lastly, a study with Lion's Mane found that the addition of 1% of the mushroom to feed for olive flounders (*Paralichthys olivaceus)* infected with *Philasterides dicentrarchi* reduced mortality rates from 90% in the control group to 30%.[36]

- **Cats and dogs:** A wide variety of immune boosting mushroom supplements have been created for felines and canines, many utilizing *Hericium* species. Homemade versions of these products can be created using the methods described in Chapter 7.

Be sure to consult your veterinarian before administering supplements to animals.

Many other studies demonstrate the benefits of integrating fungi into the diet of animals. If you care for an animal species that is not listed above, take a few minutes to search online for additional studies. You might be surprised by what you find.

Mycosystematics: The Art of Natural Mushroom Farming Design

With connections between the elements becoming increasingly tighter, the final stage in the growing knowledge net is the fruit body of implementing multifunctional mycosystems across whole backyards, community gardens, and land projects.

With so many options and applications, it can be hard to know where to start installing fungi. The most ambitious cultivators may start by installing fungi wherever space allows. But, by taking the design process slowly, and by assessing their environment like mycelium, the resilient cultivator can draw together a clear picture of the needs, limitations, resources, and goals offered by any site and from this baseline create a system that matches and enhances those unique parameters. The challenge that natural cultivation requires is that, as opposed to focusing on the short 2–3 month cycles of indoor work, outdoor projects require the capacity to think in longer time frames, anticipating the needs and changes of the environment for years to come.

By thoroughly assessing a site, mycosystem designers can determine the most efficient and intelligent means for connecting the various elements that complement mushroom installations, with the goal being the creation of a more holistic and multifaceted system. One design process that helps ensure that these considerations are adequately addressed is the mycelium-like SADIMET system used by permaculturalists and other landscape designers.

Survey

The first step in the SADIMET process is to assess the site and locate ideal areas that accommodate for as many of the fungal needs as possible. One of the biggest determining factors of what species can be grown at a given site is the local climate and its extremes. How does the temperature of the site change throughout the year? What is the temperature during the rainy season? How much rain falls during this time? Will these limiting factors provide the fruiting requirements of the species you wish to grow? If not, are there other species/strains that can fruit in the local climate?

For most mushroom species, the ideal site will be in full shade, cool, relatively humid, and with nearby water and/or substrate access year-round. While some mushrooms tolerate dappled or partial sun exposure, full shade will not deter these species and will help maintain higher levels of substrate moisture and relative humidity. Be sure to account for changes in the site's shading that occur throughout the day and year as the sun moves through the sky. The highest point that the sun reaches in the middle of winter is much lower in the sky than its highest point in the height of the summer months. Thus, a site found in deep shade throughout the winter might be in full sun for longer hours during the summer. Noting this fluctuation in shade will help ensure that fungi installed in late autumn will not get sun baked due to poor planning when the summer sun comes shining.

An easy way to approximate this solar movement is with a solar compass, which can help determine the variation in solar elevation during a year. Once you have determined these maximum and minimums, you can then assess if the proposed site for your installation will be adequately shaded. If no shaded area naturally exists, structures and/or plant coverage can be designed to provide shade and a proper microclimate.

Mushroom beds should be located where the prevalence of cold and freezing and/or hot and drying winds are minimal as the dramatic shifts in temperature and humidity levels that these winds bring can significantly affect yields. Mushroom installations can be located downwind of tree rows (wind breaks) or other protective plants to help reduce the effects of wind.

These overstory plants should be considered for their effect on an installation as well. Coniferous trees, such as cedars, can significantly limit rainfall from reaching the understory while their needles can acidify substrates and potentially limit mycelial growth. Deciduous trees can help shade installations in the summer months and yet still allow for heavy rainfall to hydrate the install in the wetter months when the leaves have fallen.

The proximity of the installation of the site should also be a major consideration. Mushroom beds tend to fruit spuriously and for short periods. Locating installations in areas that are regularly visited or close to centers of human activity will ensure that these temporal fruits are collected in their prime and that their general maintenance will be more frequent. The first sites I assess include the northern side of buildings, under porches, in the understory of a nearby woodlot or food forest, or on the northern aspect of a slope or berm.

Finally, sites should be surveyed for their existing resources and input requirements in relation to mushroom cultivation as well as the history of similar practices. Other questions to consider in this regard include: What substrates are locally abundant or scarce? What fungi have been successfully cultivated by others in the past under similar conditions? What hasn't been tried? What species/strains are locally abundant? How much time and energy will be required to modify the site to be suitable for mushroom cultivation? How abundant are indigenous mycorrhizal fungi? What potential competitors are present? Where are there accessible spaces for efficiently storing materials or integrating other design elements?

Assess

With the site surveyed for its influences and limiting factors, informed decisions can now be made to determine specific goals that the land and available resources can accommodate. This is when specific species/strains are identified for cultivation, installation locations are finalized, water access and management systems are designated, and other design elements are selected to support the mycosystem. If you plan to use your installations for educational purposes in the future, determining how to match these additional goals is best done at this early stage.

Design

The third step is to construct the actual plan for how the goals set in the assessment stage will be accomplished in a manner that is as efficient as possible. If you are just starting out in this process, it is helpful to get feedback on your designs from other mycologists, permaculturalists, or living systems designers. Otherwise, the following are a few tips that can help most mycosystem designs.

Efficient placement of each element is the key to success. Placing installations downhill from water or substrate sources reduces the need for energy inputs as the movement of these resources is facilitated by gravity instead of human labor or fossil fuels. Incubating and fruiting mushroom logs near ponds or swales will reduce the need to move the logs far in order to soak them.

Consider how to make the system self-sustaining. Integrate quick growing substrate sources such as alder trees into the design. These trees can provide shade and humidity in their initial years and later be felled for substrate use as other trees take their place. Think durationally. Recognize that mycorrhizal associations increase in benefit over several years.

Implement

With a sound design finalized, the actual labor of installing the mycosystem can now commence. At this stage funding is collected, materials are purchased, labor is hired, substrates are prepped, and ground is broken as fungi are bought in to enhance the vitality in the landscape.

Maintain

Once an installation is in place, it should not be left to fend for itself, at least initially. In the initial months, and occasionally thereafter, the installation should be given regular attention to ensure that it is establishing well. Additions of water, fertilizer, amendments, and extra substrates may be added to installations as needed as other elements of the system are updated, repaired, replaced, or repositioned to increase functionality.

Zones of Fungal Homes

A helpful method for determining the placement of elements in a mycosystem is to locate a given resource in an area that is visited with the same degree of frequency as the element requires attention. In permaculture design, six zones of human activity are generally delineated to provide this conceptual framework for siting elements. As generic guides, these zones do not need to be of a distinct size, nor may all of them be present in a given location. Rather, zones are considered abstract boundaries that flow together in a gradient of human presence that can vary by the day or season. Whether you live on 1/16 of an acre or 60 acres, the elements of your system are best located in areas that match both your needs and those of the fungi.

- **Zone 0 (The Home):** Here, in the center of human activity, spawn is cultivated and indoor fruiting environments are established. Fungi are cooked or prepared for storage, medicines are made, and cultures are maintained.
- **Zone 1 (The Garden):** This area is typically the most intensively used, managed, and visited outdoor zone. Often located close to the home, Zone 1 is ideal for edible and medicinal mushroom installations. Bulk spawn can be maintained in greenhouses or outbuildings and a log fruiting area may be established. This zone also includes the path to vehicles, greenhouses, or other regularly traveled areas.
- **Zone 2 (Orchards):** In occasionally visited tree lots and food forests, inoculated logs are set to incubate near water sources. Trees are inoculated with mycorrhizal fungi and mushroom beds are placed between rows (fungalley cropping).
- **Zone 3 (Major Crops):** Farther out, AM fungi are grown in pot culture and used to inoculate annual and perennial crops. Zone 3 on larger properties tends to include pastures, animal forage areas, dams, and water storage areas that provide water and substrates to installations.
- **Zone 4 (Managed Rangelands):** Here, quick growing trees are inoculated with mycorrhizal fungi and grown over years until they are selectively harvested for mushroom cultivation. Stumps and snags are also inoculated with mushrooms to reduce fire risks and increase fodder for wildlife.
- **Zone 5 (Untouched Wilderness):** This zone is where the cultivator comes to learn from the fungi in their wild habitat and collect new cultures. Here, Nature's guidance shines at its brightest to show Radical Mycologists how to refine their designs to better mimic natural patterns. The wild provides a link to the wisdom and spirit of Nature and acts as a reminder of the interdependent system that is Earth. This is the forest and bushland that is free of human intervention, interference, and control. This is where our spores return.

Evaluate

During maintenance, examine each aspect of the system to determine what is working well and where improvements can be made. Are the initial goals of the design being achieved? Do the goals need to be updated? What should be changed, added, or removed to increase the efficiency of the system and/or achieve its initial goals?

Tweak

Based on your evaluations, you may choose to modify the system's design. The Maintain, Evaluate, and Tweak stages represent a cycle that is always evolving and never finished. These three stages essentially occur simultaneously as the cultivator comes to learn from the fungus' needs and responses as the environment changes over time.

Remember that the maps you draw and the designs you establish at a desk may not be the best one for the land itself when you finally begin engaging with it. Natural mushroom farming is not a process of determining the future of a landscape, but one of myceliating that landscape with your best intentions and a respect for the creatures that have, do, and will live there. Start slow and with tangible goals—low hanging spores—and build from there as you keep an eye toward the long-term goal of creating a resilient mycosystem that is dynamic, multifaceted, and founded in a deep relationship with the fungi and the land that you inhabit.

Natural Mushroom Farming in Extreme Environments

Mushroom cultivation is, in many ways, an attempt by the cultivator to closely mimic the natural habitats of fungi. While many of the techniques in this book reflect the species, climate, and substrates found in temperate regions, the translation of these practices into more extreme climates is not as difficult as one may assume.

In arid regions, dryland cultivators can adjustment their designs to compensate for a relative scarcity of water. For in-ground installations working with wood-lovers, the following features can help reduce the effects of high heat and low water reserves:

- Position installations in low-lying, shaded areas. Beds should be lined with a double layer of thoroughly hydrated cardboard to mitigate the drawing effects of the surrounding, drier soil. Sink the bed 8 inches (20 cm) below the soil horizon to help capture water into the bed and slope the edges of these beds to reduce their erosion in the event of heavy rain storms.
- Incorporate hydrated biochar and larger pieces of fresh wood into the substrate at spawning to help provide longer-term water sources to the bed during times of drought.
- Provide sufficient shade protection along the southern and eastern sides of the bed, if not around its entire perimeter. Installing these plants in a deep layer of rich compost and applying a thick mulch layer will help support the plant's growth while also building a water sink with the organic matter. This sponge will later help hydrate the ground surrounding the mushroom bed, thereby reducing the drawing effect that the otherwise dry soil would have on the installation.
- Local species/strains that can tolerate the local climate should be emphasized. Otherwise, stress tolerant species such as Shaggy Mane and King Stropharia are good candidates for importation. Conks and tougher flesh mushrooms tend to be more tolerant of drier conditions. Vigorous species can be acclimated to digest cacti and other desert shrubs as a substrate.
- Mycorrhizal fungi and truffles should be incorporated into arid plantings if possible as they directly contribute to the survival of plants in such stressful climates. *Pisolithus tinctorius* is suggested for pine and eucalyptus trees as this fungus can tolerate up to 100°F (38°C).

Volvariella volvacea, Coprinus cinereus, Stropharia rugosoannulata, Pleurotus tuberregieum, *and* P. cystidiosus/abalonus *can all be grown at or just below 86°F (30°C).*

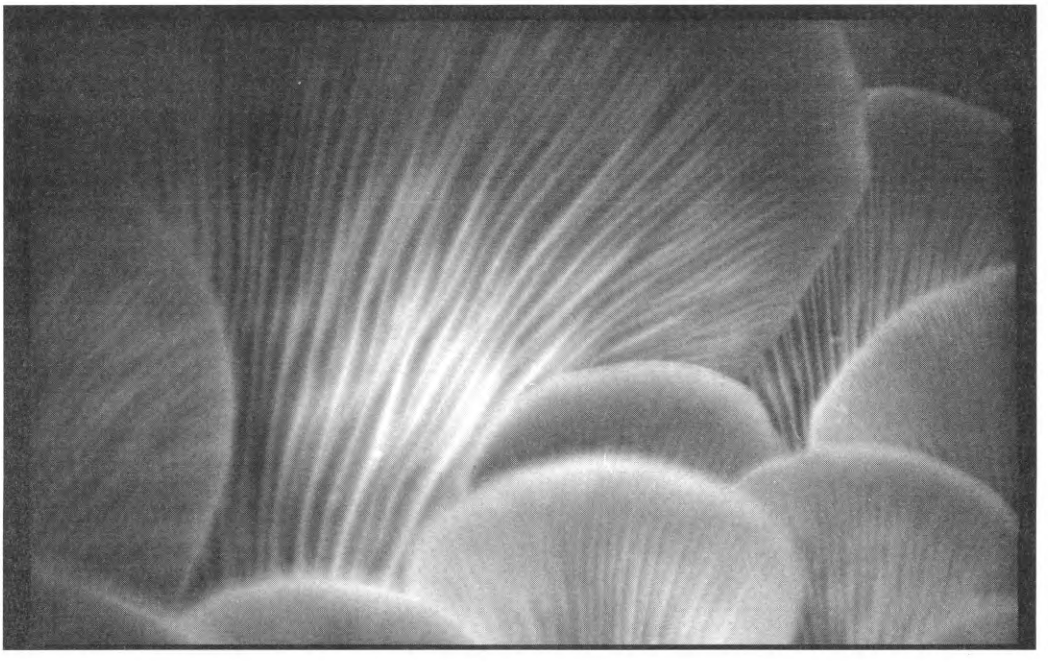
A suggested route for accomplishing some of the needs of aseptic work in developing nations is to ally with Rhizobia *cultivation operations, which are both common in many countries and also use practices and tools that are similar to those required for grain spawn production. Beneficial* Trichoderma *species can be cultivated on a variety of simple substrates that require little preparation.*

In addition to the above suggestions, all mushroom installations should be well hydrated in the initial months to ensure that their minimal water needs are met and that the mycelium is able to establish. As the mycelium spreads through the landscape, their surrounding plant allies climb upward, spreading shade across the installation, cooling the soil and substrate, and reducing topsoil loss caused by desert winds. As soil is built over the seasons, more plants can be introduced, drawing the edge farther from the center of the mushroom installation and eventually enabling the support of an entire food forest. In time, an oasis is formed in the once barren desert where life is able to flourish and food and fungi are found in abundance.

Another challenging environment for mushroom cultivation is in non-industrialized nations where many of the resources required for mushroom cultivation are difficult, if not impossible, to acquire. In places like these, cultivators must get creative and adapt the concepts in this chapter and Chapter 8 to the challenges they are faced with. Developing substrate formulas, tyndallizing or solar pasteurizing substrates, and bulking up indigenous strains are some of the first steps toward mycoresilience in these regions. In fruiting environments, cool air can be drawn up from underground aquifers that can also supply water and humidity. In the Middle East, such systems are known as *qanats* and have been used since 100 BCE.

Doing outreach and education around the benefits of working with fungi is often helpful for gaining support in these parts of the world. It is best if this outreach is contextualized to local issues. For example, mushroom compost is often used as a growing medium for plants in Java, Indonesia where volcanic rock-rich soils predominate. Oyster mushrooms have been shown to fruit from over 200 agricultural "waste" streams including corncobs, grass, sugarcane bagasse, sunflower seed hulls, cotton waste, rubber tree sawdust, peanut shells, cactuses, oil palm waste, and water hyacinth plants. Coffee pulp is a major waste stream in many tropical countries but, due to the presence of lignin and phenolic compounds, this potential fodder source cannot be fed to most animals. The fermenting effects of mushroom mycelium can break down these harmful compounds, releasing the carbohydrates, proteins, and minerals in the pulp. Mushroom cultivation is a farming practice that can be taught to people of all backgrounds and physical abilities.

There are manuals dedicated to mushroom cultivation for people with physical disabilities in developing countries.[37] Free online mushroom cultivation books from Aloha Medicinals detail some of the farming practices in various countries such as Zimbabwe, India, Nepal, Thailand, Swaziland, Uganda, and Kenya.[38] These books focus on larger operations for these countries but help demonstrate how mushroom cultivation can be adapted to different regional constraints.



TLC

Fungal installations need not be purely utilitarian or linear. Shown below is a mushroom labyrinth designed by the author and implemented at Tryon Life Community farm in Portland, Oregon. Each of the four spiraling arms begins and ends at one of the four directions, approximating a golden curve and carrying a mushroom species that reflects the flora of the seasons. Morels for the East/Spring, King Stropharia for the North/Summer, Elm Oysters for the West/Fall, and Pearl Oysters for the South/Winter. At each entrance, a welcoming birch log myceliated with Turkey Tail. At the center, a clearing for rest and four options for a return to the world beyond.

Chapter Ten

Fungi for a Future

Unless someone like you cares a whole awful lot, nothing is going to get better. It's not. —The Lorax

Fungi break down plastics, degrade toxic pollutants, and heal damaged landscapes—remarkable traits that result from their potent digestive capacities and extreme resilience. In combination with the skills of the last two chapters, Radical Mycologists can integrate these pollution-reducing fungal abilities into living systems that support their home community or environment and thereby *mycoremediate* pollutants in their landbase. When added into *bioremediation* installations that incorporate remediative bacteria and plants, fungi intiate and close nutrient cycles that lead to an environment's recovery. In allyship with those they live with, fungi act as the navigators of a habitat, steering its course through the impacts of human activity and natural disaster and toward regenerative states of greater health.

As a study, mycoremediation is nearly a century old, with hundreds of studies and scientists having contributed to the field. Today, it is well established that micro and macro fungi across phyla can sequester heavy metals and destroy carcinogens within a matter of hours or days. And yet, though these findings strongly suggest a significant fungal potential to mitigate much of the world's pollution, few large-scale applications of these discoveries have been developed in the field. The vast majority of mycoremediation research has been limited to small-scale, proof-of-concept models conducted under controlled conditions. As with other sciences, funding and researchers remain limited, while the patenting of effective techniques limits the ability of individuals or groups to turn their understanding of the science into a living.

Information on mycoremediation has also been remarkably inaccessible, with the few books that adequately discuss the topic being prohibitively expensive and daunting due to their highly technical tones. Mycoremediation's unavoidable chemistry is also a major setback, especially for grassroots bioremediators unfamiliar with this endlessly intricate science. And with few educators on the subject, many enthusiasts have been left to develop mycoremediation experiments on their own, often with limited success. To counteract these barriers to access, the nuances of mycoremediation need to be clearly and effectively conveyed and understood by Radical Mycologists who wish to advance the field. Once this hurdle is overcome, the scalability, speed, low cost, elegance, and efficacy of the practice become readily available to anyone desiring to enhance their land and life. Through a study of the science of fungal digestion, Radical Mycologists can offer their communities the ability to truly recompose a new world from the rubble of the old.

Mycoremediation at a Glance

Surveying the large number of studies on fungal remediation can be a bit overwhelming. Still, much of the research focuses on just three broad types of pollutants:

- **Microbes:** The antimicrobial properties of mycelium can be easily and inexpensively employed to trap, neutralize, and/or kill pathogenic microbes in water systems. The application of fungi to mitigate plant pathogens is addressed in Chapter 9.
- **Metals:** Heavy metals are chemical elements that have negative effects on the health of living organisms. Many fungi can stabilize heavy metals in their substrate and/or remove them entirely. Heavy metal contaminated water can be "filtered" through fungal mycelium to reduce metal concentrations. Attempting to remediate heavy metals with fungi is relatively simple in theory. In practice, however, the complexity of heavy metal chemistry requires designing remediation protocols that are often challenging and site specific.
- **Chemicals:** Fungi from a range of genera and niches naturally produce extracellular metabolites that have been shown to degrade a wide variety of industrial pollutants. Chemically contaminated water can be treated using methods similar to those for liquid culture cultivation. Contaminated soils can be mixed with fresh substrates and spawn to be remediated *in situ*. This promising and fascinating aspect of mycoregeneration is relatively simple in theory and practice yet requires further refinement for large-scale field applications.

Holistic Remediation

Like all who struggle for a healthier world, the fungi need support, collaboration, direct communication, sound alliances, and a diversity of tactics among their habitat's co-creators to create the most significant and positive changes in their environment. The plant, animal, and microbial inhabitants of an ecosystem play an array of unique and important roles in the cycling of nutrients. The remediative work of fungi is rarely isolated from these interdependent, multi-trophic labors. To reflect the various facets of natural regeneration cycles, robust fungal remediation designs must account for all of these living and non-living varibles and their potential impact on the long-term success or failure of an installation. To this effect, the following elements elaborate upon the design concepts presented in Chapter 9 to significantly enhance the success of fungal remediation strategies.

Microberemediation

While fungi are the heavy hitters when it comes to degrading complex chemicals, bacteria are commonly applied to digest many simple hydrocarbons and low-molecular-weight aromatic compounds. Various alkanes, branched alkanes, and cyclic alkanes, as well as the aromatics benzene, toluene, ethyl benzene, and xylene (BTEX) can all be digested by common species of bacteria. Singh summarizes the ease with which microbes degrade simpler hydrocarbons as *n*-alkanes > branched alkanes > low-molecular-weight aromatics (e.g. BTEX) > cyclic alkanes.[1] If the chemical that you are addressing is one of these compounds, the application of remediating microbes offers an approach that is generally more time, labor, and cost efficient than fungal remediation strategies.

The best combination of remediating bacteria has been identified as *Pseudomonas fluorescens* (produced in the casting of redworms) and various *Bacillus* species (commonly found in leaf litter). To create a remediating microbe inoculum, simply incorporate worm castings and a few handfuls of leaf litter into an actively aerated compost tea recipe, as described in Chapter 9. Twenty-four to 36 hours later, the resulting tea can be applied to the polluted site or, better yet, sprayed onto an aerated (hot) compost pile that contains the contaminated substance. If the compost pile is properly built with a C:N ratio of around 30–35:1 and re-inoculated with this compost tea at each turning,

the reduction of contaminants can be quite rapid. The addition of adding pre-grown microbes to perform a remediation task is known as *bioaugmentation*.

An additional, experimental step would be to safely sample a handful of soil from the contamination zone and add it to the initial compost tea recipe. This polluted soil will, in theory, be host to various bacterial species that have adapted to the contaminant. When incorporated into the tea brewing process, these microbes will multiply along with the bacteria derived from the castings and litter and exchange their genetic material through a process known as *plasmid transfer*, essentially co-evolving in the process. The resulting brew will thus contain known remediative microbes that (theoretically) now contain site-specific adaptive traits gleaned from the species sampled from the soil.

For more complex contaminants, microberemediation can be applied to contaminated substrates and soil once fungi have run their course. Fungal remediation often breaks down large chemicals into smaller constituent parts that can be quickly and efficiently treated with microbes using the above techniques. Bacteria should not be applied to contaminated substrates prior to inoculation with fungi as the micobes may harm the fungi, reducing a design's efficacy.

Phytoremediation

Plants perfom several remediative functions that enhance the health of micro and macro ecologies. Many plants uptake volatile compounds from the soil and subsequently release them into the atmosphere during respiration. Approximately 400 plant species sequester toxic metals into their tissue. These heavy metal laden plants can later be harvested and treated *ex situ*. Plants also play a critical role in supporting the remediative work of mycorrhizal fungi and other soil inhabitants. Their incorporation into holistic remediation strategies should be accounted for in designs when possible. Sunflowers are a simple and common choice for targeting PAHs, lead, mercury, copper, cesium, chromium, nickel, and zinc. However, sunflowers alone will not quickly fix a contamined soil system. For more information on grassroots phytoremediation, see *Earth Repair* by Leila Darwish.

Vermi-remediation

Worms raised in vermiculture systems can be directly placed into soils that are transitioning from suppressed to refreshed states where they will help churn and aerate the soil, supporting the mycorrhizal fungi and other microbes present. Worms are quite sensitive to environmental pollutants, however, and should not be employed in the initial stages of remediation. Their application is best reserved for later stages when toxicity levels have been reduced and natural regeneration cycles have begun to arise. The combination of spent mushroom spawn and worms has been shown to synergistically reduce PAHs by up to 99.99%.[2]

Biochar

The beneficial physical and chemical properties of biochar discussed in Chapter 9 readily extend to remediation designs. Numerous remediation studies utilizing biochar alone or in concert with beneficial microbes suggest that biochar provides substantial benefits to remediation strategies that seek to sequester toxic compounds and support soil ecologies. Remediation research with biochar is in its infancy. To develop the best protocols, more experimentation is needed to determine the appropriate pore size, application rate, and inoculation method for pollutant- and habitat-specific biochar applications.

Mycoreactors

The oxygen requirements of fungi limit the average depth of a remediation installation to approximately 3 feet (1 m). Where spill zones or contaminant piles extend beyond this depth, a means for introducing oxygen must be applied. One such system, known as a mycoreactor, has been designed and patented by Mia Maltz and Bob Rawson, founders of the Amazon Mycorenewal Project.[3] My-

coreactors are plastic tubes of any length or diameter that have been perforated with holes 0.25–0.5 inches (0.6–1.3 cm) in diameter and subsequently placed throughout an installation to increase aeration in the soil. For *in situ* designs, holes must be excavated to place the mycoreactors in the ground. Alternately, constructed piles of contaminated substrates can be built around these tubes. An elaboration on this concept is to construct a "jungle gym" of drilled PVC pipes around which a pile is constructed, thus providing passive airflow throughout the entire pile. Moisture levels in the substate should be monitored if the system is heavily aerated.

Sorbing Soils

As a large percentage of remediation work deals with treating contaminated soils, it is helpful to have a basic understanding of how soils develop and how they can influence, or be influenced by, remediation efforts. Soils contain rocks, sand, silt, clay, living organisms, and organic matter in various stages of decomposition. As these components grow and erode, they digest and affect each other, permeating the soil matrix with countless organic and inorganic compounds that make life possible for plants and higher organisms. However, not all soils are created equal. With their unique chemical properties and wide variability, the balance of nutrients and ions produced through decomposition not only influences which plant communities the soil can support, it also determines the degree to which a chemical or heavy metal will be held in the soil as well as how easily such contaminants can be removed. Typical soil layers include:

- **Organic layer:** Up top are accumulated dead plant and animal remains in early stages of decomposition.
- **Topsoil:** Just below, organic matter in later stages of decomposition mixes with minerals in small- to medium-sized particles.
- **Subsoil:** Deeper, this layer contains a larger percentage of mineral deposits than the topsoil layer.
- **Parent rock:** Beneath subsoils, larger rock pieces predominate. This layer provides much of the soil's mineral content.
- **Bedrock:** At the bottom, solid rock remains that cannot be excavated by hand.

Minerals: Big Rocks, Little Rocks

The mineral portion of soil is produced by the slow erosion of parent material to sand, silt, and smaller particles. The smallest end products are primarily silica and alumina compounds that are liberated from silt and coalesce through their electrical attraction to form flat crystal platelets. As these platelets grow in number, they stack in layers to form clay. There are several types of clay, each with their own unique chemical properties. In all types, however, silica and alumina sheets tend to predominate.

The mineral portion of soils often reflects the age and eroding factors of the surrounding environment. In arid regions, minerals are primarily found as sand and rocks, while older soils or climates that produce more rain tend to host a higher percentage of clay. Clays can chemically bind to both negatively- and positively-charged ions, giving them the ability to retain a significant amount of water, nutrients, and pollutants from their environment.

The silica and alumina compounds in clay are made with a "shell" of oxygen atoms. When these molecules connect to form the sheets that make up clay, their outer edges project oxygen atoms that carry a slightly positive charge. When a negatively-charged anion of a given metal, mineral, or polltutant encounters these positively-charged sites, the anion will become bonded to the clay's edge. In contrast, the surface of clay sheets tends to have a net negative charge due to the swapping of the Al^{3+} or Si^{4+} atoms in the clay's surface compounds with cations of a lower charge. For example, the Al^{3+} in the center of an alumina compound may be exchanged with a Mg^{2+} ion that passes by the clay surface, ultimately leaving a charge of -1. This process of swapping out positively-charged ions (cations) is known as cation exchange and the measure of a soil's cation-exchange capacity

(CEC) determines the quantity of nutrients it can hold. The CEC of soil is in constant flux due to the influence of various factors such as the pH, water concentration, and the microbial population at any moment. These CEC fluctuations directly influence how heavy metals will interact in the soil. Soils with a high CEC have a high potential to sorb positively-charged metal ions. Sandy soils with a low CEC do not hold metals strongly. Very young clays (such as those found at the bottom of a dry river bed) and very old clays often have low CECs. When metal cations stay bound in these soils they are said to be mobile, meaning they easily move into ground and surface water and ultimately into living organisms.

The ability of a given metal cation to exchange in the surface compounds of clay increases with that metal's valence, atomic weight, and ionic potential. The following sequence represents the priority (affinity) that a given metal receives during cation exchange in clay minerals: $Cu^{2+} > Cd^{2+} > Fe^{2+} > Pb^{2+} > Ni^{2+} > Co^{2+} > Mn^{2+} > Zn^{2+}$. Thus, CU^{2+} is more readily exchanged than Cd^{2+} or Zn^{2+}. Cation exchange can occur inside the clay's sheet layers or on the surface of the clay, depending on the structure of the clay.

Organics: The Recomposition of Life

The organic portion of a soil system is comprised of plant and animal tissue in various stages of decomposition. This fraction can have a CEC 4–50 times higher than clay (by weight). The organic materials with the highest CEC are small, complex carbon structures known singularly as humic substances and collectively as humus. Humus is the dark, amorphous substance that remains after the insects, fungi, and microbes in the soil web have eaten as much of the organic matter as possible. It is comprised primarily of polysaccharides and humic acid.

Humic substances no longer share any recognizable traits of the plant tissue that they once comprised and they seem to degrade very slowly, leading to the assumption that humus is one of the last stages in decomposition. With many positively- and negatively-charged sites surrounding its surface, humus acts like a sponge for the soil that can hold and release many times its weight in water and nutrients, directly controlling the amount of plant life that the soil can support. This sorbing capacity also influences the quantity of chemical pollutants and heavy metals that a given soil will hold.

Soils also host an array of ligands (e.g. SO_4^{2-}, Cl^-, OH^-, PO_4^{3-}, NO^{3-}, and CO_3^{2-}) that will temporarily bind to heavy metal ions through a process known as *precipitation*, only to later release them back into the soil via *dissolution*. This *precipitation-dissolution cycle* occurs at varying rates for any given portion of a soil web and is directly influenced by the pH and CEC of the overall environment.

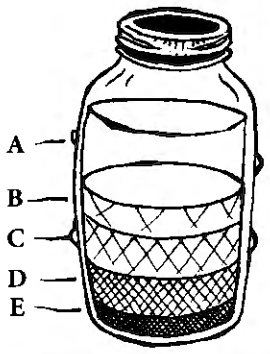
Life: Big Bugs, Little Bugs

Bacteria also influence the CEC of soil as their digestion plays a significant role in the final stages of humus formation. However, the organic acids that these microbes secrete to digest organic matter are only effective in certain pH ranges. If the pH of the soil becomes too acidic, these organic acids are less effective. The result is a decreased rate of humic substance creation and, ultimately, an overall lower CEC in the soil. Such soils are said to have a pH-dependent CEC. This factor holds a long-term influence on the soil and is not something that is easily controlled through remediation installations.

Determining Soil Type and Measuring CEC

Considering the influence that each fraction of a soil can have on chemical and ion retention, it is helpful to determine the approximate ratio of minerals to organic matter in a soil that is being remediated. This can be done with a "settling test" in which the fractions of a soil sample are separated in water to provide a visual approximation of the soil's composition.

1. Collect a few handfuls of non-contamined soil from outside of the contamined zone that seems representative of the contaminated soil.
2. Dry this soil and then remove any large roots, rocks, etc.



After a soil test has settled, distinct layers will appear, with their relative size reflecting the composition of the soil.

A – Water
B – Clay
C – Silt
D – Sand
E – Rock

3. Fill the bottom 1 inch (2.5 cm) of a quart-sized mason jar with the soil.
4. Fill two-thirds of the jar with water.
5. Add a pinch of salt and shake vigorously.
6. Set the jar down and let the particles settle. Clear zones will be visible within a day or two. Sand will be on the bottom of the jar, followed by silt, and then clay on top. The relative heights of these layers represent the proportion of these constituents in the soil as whole.

For the greatest accuracy, determining the CEC of a soil sample should be done through a soil testing facility. Most cooperative extension offices offer this service. If one of these offices is not available in your area, your local farming association should know where the nearest soil testing facility is located. CEC testing is commonly used by farmers to determine the maximum amount of fertilizer that a piece of land can retain.

Analyzing the Results

The type of soil you are remediating and its CEC directly influence the design and overall effectiveness of a given remediation strategy. For example, if a soil is primarily composed of sand with a low CEC, you can assume that many compounds will not be tightly bound in the matrix. In this case the soil could potentially be excavated and "washed" of the contaminant, a rather difficult and unnatural process. It can also be assumed that some portion of the contaminants spilled on soils with a low CEC will readily leach out of the soil with rain and enter the water table and/or surface to travel across the soil horizon. In this case, habitat buffers with a high surface area and CEC (e.g. swales filled with inoculated sawdust/woodchips and straw) can be constructed to capture these mobile contaminants. Conversely, soils with a high organic content or high CEC in general can be assumed to be holding a large percentage of the compounds that were spilled on them. These soils will require targeted and potentially long-term remediation strategies that address the specific pollutant or array of toxins known to be present in the soil.

A Standard of Care

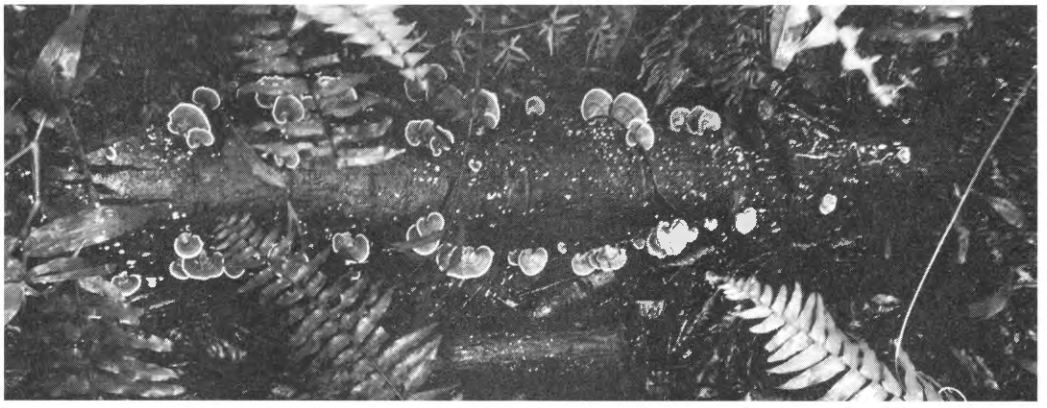
Grassroots mycoremediators, like fungi, are healers of a dual nature. As the first responders to a damaged environment, they address the immediate threats to a habitat's survival and apply short-term remedies that prevent greater injury. In their surveying and diagnosis of a sickened landscape, remediators act as doctors of the Earth, prescribing long-term treatment plans for entire ecosystems and their surrounding communities. In each of these facets, the remediator acts in service to the land and the human and non-human communities that depend on its fertility. Bioremediation work is the health care of an ecosystem. And as such, bioremediators should be held to a standard of care—a set of ethics or guiding principles—that ensures the safety and autonomy of those being treated as well as the advancement of bioremediation as a respectable, well-founded practice. The following seven guidelines are suggestions for framing a high standard of practice amongst grassroots bioremediators.

Do No Harm

As healers of landscapes, the primary oath of the remediator should be the same as that of the physician: do no harm. Remediation work should seek to improve an environment, not cause deleterious effects. This may seem obvious, but it is easy to implement remediation designs that do not fully consider the potentially negative impacts that a given element may have in the short- or long-term future. Accidents and unforeseeable consequences happen and may be unavoidable to some degree. Thus, caution and thoroughness should be emphasized when designing a remediation strategy to avoid problems as best as possible. This ethic extends to the remediators themselves. Grassroots remediation work is inherently dangerous and personal safety measures are imperative to protecting the health of remediators and ensuring the advancement of the field.

Work With Nature, Not Against it

Nature responds to change and challenges in ways that humans cannot anticipate. The intelligent and elegant adaptations that plants, fungi, and microbes produce in response to even the most devastating conditions provide deep insights into the needs and capacities of a given site. Thus, remediators should reflect upon and support these spontaneous regeneration cycles to create designs that honor and incorporate the lessons offered by the local ecology, better enabling one to ally with the ecosystem, rather than blindly attempt to command its destiny.



Mushrooms fruiting from a log stuck in an Ecuadorean oil pit.

Respect the Fungi

With their incredible adaptive capabilities and numerous means for increasing ecological resilience, fungi tend to take on an aura of indestructibility for many pro-myco remediators. For some, the phrase "Apply fungi" may sound like an obvious solution to any ecological problem. However, as powerful as the fungi are, their gifts should not be overstated or abused. Fungi are living, fragile creatures with biological needs and physical limitations; they require support, food, shelter, and a dynamic ecosystem to ensure their long-term survival.

Their remediation capacity is also quite limited. Fungi cannot remediate every industrial pollutant in the world and of those they can degrade, it is often not to 100% efficiency. To cast spawn on a pollution zone and wait for the fungi to do all the work does not account for their basic needs. To ignore these needs and act as though fungi can perform remediation miracles is to ignore their limitations and shoulder them with the burden of human endeavors and environmental mismanagement. In such instances, fungi become a bandage for the world's wounds that enables the economic and political influences that cause disasters in the first place to go unaddressed. Without a thorough reflection on these parameters, the fungi can become a tool to be "used," a "green" technology of biomass to be patented, and a quick and easy fix for incredibly complex problems. The grassroots remediator can break this dynamic by respecting the fungi at all stages of their remediation design. To treat fungi as allies and work with them in a common struggle for a healthy world, remediators must diligently ensure that their understanding and explanations of fungal remediation strategies are accurate and based on sound scientific evidence.

Respect the Afflicted

The greatest personal and social impacts that arise from an environmental disaster occur in the human and non-human communities that surround or live downstream from a contamination site. With their cultural and historical ties to the damaged landscape, these communities should thus be seen as gatekeepers to the development of any potential remediation strategy. When grassroots remediators approach an afflicted community that is not their own, it should be recognized that the remediators likely have a distant or non-existant relationship to the disturbed land and local culture. From this place of difference, it is important that the first step in developing a remediation

plan is to establish a positive relationship between all parties.

Before any planning commences, the affected communities or their leaders should be approached directly and asked if help is even wanted. Overly complicated or technical explanations should be avoided and a clean description of what is and is not possible should be stated. Honesty, consistency, accountability, compassion, and respect are central to developing any long-term relationship in this case. The community has likely been devastated by the environmental disaster, misled, or lied to by the responsible parties, and otherwise dismissed by official representatives. It is quite possible that they may be distrustful of outsiders who claim everything can be fixed with bacteria and mushrooms.

Some of the worst industrial disasters in the world have been located near communities of minorities or marginalized demographics and often go unreported by the media or are poorly managed by the responsible parties. Remediators who have greater access to resources, media coverage, or governmental influence than the communities they are working with should consider asking the affected group if these priviledges may be of benefit to the community's immediate or long-term needs. It is important, however, that the help not be considered an act of charity. Rather, extending one's resouces and abilities in an open, respectful manner should be seen as an attempt toward building a personal degree of allyship with the afflicted group in an effort to honor and support their pre-existing means for increasing their own resilience.

Resist the Inflictors

Grassroots bioremediation does not begin or end with healing the damage caused by a disaster. Along with these acts of increasing community resilience should come an ethos of community resistance that seeks to eliminate the practices that enabled such disasters to occur in the first place. This is the preventative medicine that eliminates the potential for future ills to arise.

Major environmental disasters are not due to the careless practices of the average person. While the spills that come from car, train, and tanker accidents may be blamed on their drivers, the true source of these accidents is found in the legislation, monetary influences, and cultural values that justify their occurance. The companies that exploit natural resources, develop short-lived products, and rely on toxic chemicals for their manufacturing and farming practices are allowed to follow such short-sighted practices due to the support of a populous, economic system, and government that values the perpetual growth of a nation's gross domestic product over the long-term health of the environment. The profit-drive that fuels capitalistic economies encourages the use of unstainable means for preparing, transporting, and cleaning up industrial toxins. Simultaneously, government legislation defends these profits through crafting minimal requirements for conservation and remediation efforts from destructive parties. When these practices and policies are rationalized by the media and schooling system, these illogical standards are further reinformed. The result is limited room for questioning the outcome of such cultural assumptions or the relevance of seeking alternative social models that ensure a healthier future.

Remediators can help address these greater issues by aligning their efforts with grassroots movements working to develop alternative economic systems that value the health of the entire planet over the profits of the few. Forming direct action and educational campaigns that help slow or block the ability of organizations seeking to violate the sanctity and health of the Earth is an act of defending the few wild places that remain in the world. Such acts transform grassroots bioremediation efforts from occasional, short-lived reactions to immediate threats into a long-term, solution-oriented cultural value that enhances the related struggles of all Earth's people. The effort to defend Earth is a long one in our current era. But, like the fungi, we must persist, adapt, and continue to strive forward in the search for better means of survival.

Design Accessible, Intelligent, and Elegant Systems

Due to the technical language and expensive costs that surround most bioremediation work, many communities impacted by pollution disasters have historically been unable to access the benefits of low-cost remediation strategies. To make bioremediation accessible to people of all backgrounds, remediators should seek to lower the theoretical and practical barriers to accessing these skills by creating remediation designs that are safe, replicable, cost effective, translatable, and easy to manage for the novice. Designs should also reflect the known remediative capacities of fungi, as evidenced in the numerous mycoremediation studies available through peer-reviewed journals. And designs should account for the variations in needs and limitations that a given site will present by clearly addressing where modifications may be made on a case-by-case basis. There are few *in situ* remediation strategies that apply in all climates and conditions.

Share Openly and Publish Early

Grassroots bio and mycoremediation are in their infancy. With few real-world applications of mycoremediation strategies, many protocols are still being refined as research continues to increase. Applied bioremedation will likely become a more valuable, common, and necessary skill set in the coming years if the current trends in resource and land management practices around the world are any indication of future trends. To enhance the rapid development of refined protocols, theoretical remediation models need to be distilled through experimental trials in the field and their results shared openly with the world. Open source digital platforms that allow for the transparent distribution of mycological knowledge and remediation techniques will provide the easiest means for tracking this progress while encouraging the development of novel approaches. Web forums and wiki databases will likely be central to this effort as they provide the most efficient means for collaborative design of bioremediation protocols with practitioners around the world. In their local efforts, remediation designers, experimenters, and practitioners should also seek to structure their meetings, cultivation sessions, and final reports with the intention to enable newcomers to readily join in the learning and design process. Finally, all designs and technical information should be kept in the creative commons as a gift to present and future generations.

Site Assessment and Case History

Following the SADIMET design process outlined in Chapter 9, the first stage in remediation design requires gathering a thorough case history of the site and to conduct a field survey. This preliminary information not only helps develop a proper remediation strategy, it also provides documentation that can later be used in legal suits against the responsible parties. Taking thorough notes and photos is encouraged. Important information to gather includes:

- **The site:** Who owns the site? Will they let you enter? What are the physical features of the land?
- **The contaminant:** What is its form, concentration, and known side effects? If the contaminant is not identifiable, testing of the soil or water will likely be required.
- **The age:** As time passes, contaminants can change their chemical properties, wash into ground and surface water systems, or become taken up into the tissues of plants and fungi.
- **Previous efforts:** If any previous efforts have been attempted by the responsible parties or affected community, what were they and what was their outcome?
- **Impacts on flora and fauna:** What have the short- and long-term effects been on the health of the local humans, animals, and plants? How have the social dynamics of the surrounding communities been impacted?
- **Legal history:** Have lawsuits been filed? Are there any legal restrictions in regards to approaching or remediating the site? What has the official response been from the local government and responsible parties? Have these parties followed up

Safety First!

Remediating the pathogenic microbes and toxic industrial pollutants addressed in this chapter is dangerous work. Regardless of the immediate environmental threats presented by a given disaster, the protection and safety of remediators must be given top priority. The courageous remediator who rushes into a spill zone without protection can quickly become ill, resulting in the loss of a team member in the short term and potentially significant health problems for that individual in the long term. Personal protective equipment (PPE) should always be worn when entering any spill zone. PPE includes gloves that have been rated as safe for the pollutants being treated, a properly fitting respirator, goggles, a hard hat, boots, and a full body disposable Tyvek™ suit or rain gear. At least one team member should be properly trained in basic first aid and CPR. Team members should also consider taking a hazardous materials training course, or "hazwoper" course, which will cover the safety measures required for properly approaching and working with industrial toxins. Hazwoper courses can be taken online and are relatively inexpensive when split among several people.

During the design, implementation, and follow up to your remediation work, physical self care should be constantly addressed to ensure all team members stay healthy. It is easy to get overly committed to a cause and lose track of basic bodily necessities such as food, rest, and comfort—an unsustainable practice with remediation projects, which tend to be long-term endeavors. Be sure to slow down when the work feels overwhelming and to frequently take a step back and acknowledge the work that has been accomplished. Where possible, seek support from others and be humble and honest with yourself if you realize that you and/or your crew might not be able to solve the problem on your own.

Detoxification is also a necessary aspect of self-care. During remediation projects and for a while after they have ended, consult a physician or herbalist for recommendations on supporting the circulation and elimination systems in your body. Milk thistle (*Silybum marianum*) seeds are a well-known herbal remedy for liver support. And, of course, many of the common remediative fungi (e.g. Turkey Tail and Reishi) are powerful immune system supporters. The lymph system plays an important role in elimination. It can be supported through basic exercise or though massaging the lymph glands.

Beyond the needs of the physical body, remediation teams may also work to address the fact that witnessing the destruction of an ecosystem can be mentally and emotionally draining. The heartbreaking and infuriating experiences that come with cleaning up environmental devastation can instill feelings of despair or anger in the remediator. In response, remediation teams should actively and openly work to create safe methods for expressing their emotional reactions. As we remediate the poisons placed upon the world around us, we must also work to cleanse the toxins that accumulate inside ourselves along the way. Confronted by irrational realities, the remediator must do all that they can to maintain their balance and to find a sense of safety and sanity as they work to create a health-centered culture.

on any promises they have made in regard to treating the site?

- **Logistical constraints:** Budget constraints, available substrates, outlets for professional assistance or guidance, access to testing facilities, immediate and long-term availability of and housing for volunteers, and needs of the effected communities should be accounted for.

Once a case history has been determined, the site should be investigated. Once on site, take a significant amount of time to observe the area and thoroughly document the following:

- What is the total surface area and volume of the contamination zone?
- How does the site smell?
- How does the contaminated area feel in your gloved hand?
- Do the present organisms look healthy or compromised in comparison to those in the surrounding, non-contaminated area?
- How has the system naturally responded? What species are lacking or are in abun-

dance in comparison to non-polluted areas?
- How have past remediation efforts affected the environment? What is the current state of those prior installations?
- What is the local weather like? How might these conditions affect the contaminants and/or installation strategies?

Finally, you will likely need to collect soil and water samples for further testing. To avoid spoiling the sample, they should be collected in clean, airtight containers.

1. Obtain fresh, sterile, sealable containers made from glass or non-reactive plastics. If these containers are not available, wash glass jars thoroughly with distilled water and castile soap then rinse them thoroughly with distilled water. Allow the jars to air dry and seal them before heading into the field for collections.
2. In the field, fill the collection vessel as full as possible and seal its lid tightly.
3. Label the containers with the exact location of where and when the samples were collected and then place them on ice in a cooler.

Once your soil samples have been taken, the last step is to document and collect fungal species found in and around the pollution zone. Keep your collections separated and thoroughly document your collection with photographs and notes. The species that can survive in the spill zone may be generally tolerant of the pollutant, if not able to degrade it directly. These are the first species that should be assessed for incorporation into remediation designs prior to the introduction of exotic species/strains. Once identified, these local species can later be screened for their remediative capacities, amplified through cultivation techniques, and applied back into the landscape to provide remediative functions.

If it is not possible to visit a site due to physical or legal restrictions, the use of personal drones or balloon mapping techniques can be used to obtain aerial photos of the site. Balloon mapping was developed by the non-profit organization Public Lab to monitor the Deep Water Horizon oil spill in 2010. Instructions on how to build your own inexpensive balloon mapping system can be found on their website.[4]

Determining Efficacy

One of the greatest challenges to the progress of grassroots bioremediation work is finding accessible and inexpensive means for measuring the degree to which a contaminant has been effectively remediated. While one can, for example, smell that a soil system no longer holds an oil-based compound, it is much harder to measure the concentration of the remaining residues and definitively state that the soil is at a safe concentration. A common route taken by many practitioners is to hire the services of laboratories. However, these labs are often prohibitively expensive. Testing is a major hurdle for many remediation groups and assessing how a given project will quantify its success should be determined early on in the design process.

Measuring Microbial Concentrations

Inexpensive water testing kits purchased online can test for total coliform bacteria concentrations or specific microbes (e.g. *Escherichia coli* or *Vibrio cholera*). These kits are generally easy to use, but may only determine whether the targeted microbes are present (but not their exact concentration). For more precise tests, contact your local water testing facility.

Testing for Heavy Metals

Heavy metal concentrations are best measured in a dedicated testing facility. In the U.S., cooperative extension offices can often test the pH, CEC, and lead, cadmium, and/or arsenic levels in a soil sample for a relatively low cost. For other metals, such as mercury or aluminum, samples may need to be sent to a soil science lab, many of which can be found online.

The concentration level of a given contaminant that is considered "safe" can vary significantly by country. Often these allowable concentrations are much higher in the U.S. than in other industrialized countries. If the results of your lab tests are determined to be safe by the testing facility, you may choose to compare these results to the safetly levels set in other parts of the world. Based on these comparisons, you may or may not choose to remediate the site. If you determine that the site is under a tolerable threshold, no remediation work is needed.

Chemical Analysis

Testing for the presence and concentration of chemical pollutants is challenging. Expensive lab tests require pre-identification of contaminants, a challenge when pollutants are unknown. The development of more refined, open-source methods for cheaply measuring the concentration of chemical pollutants is one of the most pressing areas of development in the field of grassroots remediation. The reader is encouraged to help in this reseach by contacting the author with any means for improving the alternative techniques listed below. For all of the following methods, it is recommended to take multiple samples from across the contaminated site prior to installation and at periodic intervals over the course of the experiment or project.

Qualitative

If time or funds are in short supply, a simple method for assessing the quality of a chemically contaminated soil or water sample is with your senses. Does the substance omit a distinct scent? Does it have an unusual sheen or appear oily? While wearing protective gloves, does the substance feel oily or have unusual tactile qualities? Never taste a potentially polluted substance. Track these subjective qualities over time to get a sense of whether the contaminants' concentration is changing.

Bioassay

Living organisms that are sensitive to toxins can be living indicators of a substrate's toxicity. These "sentinel organisms" include species of fish, crustaceans, worms, and plants. The germination rates of chemically sensitive plant seeds can be used to determine whether a contaminated soil sample is able to support life. If the seeds sprout, the soil is at least tolerable to these plants. If they fail to grow, the soil is likely too toxic to support other, less sensitive organisms. For the greatest accuracy with this metric, seeds from the same nursery stock of beans, peas, or corn should be planted in separate containers that are filled with either contaminated soil or soil harvested just outside of the spill zone. If a significantly lower number of seeds planted in the contaminated soil fail to grow compared to those planted in the non-contaminated soil, it can be assumed that the contaminated soil is too toxic. After a remediation effort is over, this experiment can be repeated and the results compared to the pre-treatment round. If germination rates increase in the treated soil, then it is likely that the remediation installation achieved some degree of success. For contamined water systems, hatchlings of fathead minnows (*Pimephales promelas*) are commonly used.

A more refined approach to this practice is to determine the exact tolerance threshold of the plant species, per chemical. Compounds can be run through a serial dilution to create decreasing degrees of concentration of the compound. These dilutions can then be used to water soils in which seeds are planted. When the growth habits of the plant are later observed, it can be possible to determine the concentration maximum that the plant is able to tolerate. Above a certain concentration the seedlings will begin to grow poorly and at a high enough concentration they will no longer germinate. The degree of germination and the appearance of seedlings that grow from post-remediated soil can later be compared to these assayed seedlings. Based on the appearance of these seedlings, the concentration of the compound in the contaminated soil can be approximated.

DIY Spectrometry

Every chemical structure absorbs and reflects a unique combination of colors when illumated. Spectrometry is the practice of using these unique color patterns ("chemical fingerprints") to identify a substance. Spectrometers have historically been expensive pieces of equipment reserved for institutional laboratories. However, the invention of low-cost digital cameras and the rise of open-source ethics in the application of citizen science has brought about the design of simple, yet highly effective spectrometers that can be easily built for just a few dollars. The leader in the open-source spectrometry movement for pollution detection is the international research group Public Lab. On their website, Public Lab provides instructions for how to build and use a spectrometer using a webcam, a DVD disc, and some paper.[5]

A current challenge with using these spectrometers, however, is that their measurements can

vary from one sample of a compound to another if the spectrographs are not captured in precisely the same manner. In other words, all users of this spectrometer must follow a standardized protocol when collecting samples. The Public Lab community is currently working to compile an extensive, open-source database of standardized spectrographs that will be used to help identify unknown samples. As this database expands over the coming years, it will likely be possible for grassroots remediators to collect a spectrograph of an unknown pollutant and compare it to samples in this database. If a matching spectrograph is found, the unknown compound will thus be identified, for free.

Thin Layer Chromatography (TLC)

A problem with trying to identify the pollutants in a mixture is in separating the constituent compounds. Commerical labs often use expensive high pressure gas chromotagraphy systems to separate compounds. In lieu of these machines, TLC provides a simple means for separating the non-volatile compounds in a solution. Here, small drops of a solution are placed near the bottom of a sheet of glass, plastic, or aluminium foil that has been coated with a thin layer of silica gel, aluminium oxide, or cellulose. This sheet is then placed into a shallow dish containing a solvent. Upon contact, the solvent will be drawn up the plate's coating via capillary action. As the solvent passes through the drops of the sample, the two substances combine and travel up the sheet together. Along the way, the compounds in the mixture will separate out as they travel up the plate. The result will be thin bands of chemicals on the plate. The polarity of the solvent will affect how well the compounds separate. Trying multiple solvents is recommended. In order of increasing polarity, petroleum ether, cyclohexane, toluene, chloroform, acetone, ethanol, and methanol are some of the more commonly used solvents in TLC. Once separated, individual compounds can be scraped off the TLC plate and analized with a spectrometer for identification.

DIY TLC Plates

Bake 40 grams of gypsum at 350°F (163°C) for one hour. Mix 25 grams of finely ground silica, 100 milliliters of water, and 22.5 grams of the baked gypsum. Stir well and quickly drop 1–2 milliliters of this mixture on a clean glass microscope slide. Move the slide around to spread the mixture evenly, then set the plate aside to dry. Once dried, the plates can be stored until ready to use. However, prior to use the plates must be activated by being baked at 250°F (120°C) for 30–45 minutes.

Field Testing Kits

For the constant remediator, investing in portable, small-scale soil and water testing devices can save a significant amount of time and money when compared to the slow and expensive route of lab analysis. Specific devices that can assist in bioremediation work include:

- **PetroFLAG:** This device can measure total petroleum hydrocarbon (TPH) content in soils, but not individual compounds. US$850.[6]
- **The Hanby Field Test Kit:** This product can test for the concentration of various petroleum products and PCBs to a high degree of accuracy. Hanby test results are accepted by the U.S. EPA. Two kits are offered for either soil or water; each costs US$1,295.[7]
- **Clor-N-Oil and Clor-N-Soil:** These kits test for the presence of PCBs in soil and oil. They do not express the exact concentration of these substances. US$10 for 10 tests.[8]
- **Dexsil L2000DX Analyzer:** This device accurately measures the concentration of chlorinated organics in soil, water, dielectric fluids, and surface wipes. US$4,333.[9]
- **SiteLab:** This company rents portable machines that can accurately measure com-

pounds derived from petroleum based fuels in soil, sediment, and water. Depending on the machine, rental rates are US$500–$900 per week.[10]

Lab Tests

When soil or water samples are sent to a lab for analysis, the target compounds must be preidentified. The lab will not be able to tell what is in an unlabeled sample. The cost for these tests varies per chemical and testing for multiple compounds in a single sample will cost the sum of the individual tests. To reduce these prohibitive costs, try to team up with a local university, non-profit, or other organizations that can offer free or discounted access to lab testing. Samples obtained from around the site can also be comingled and tested as a single sample. However, mixing samples will not provide a clear understanding of how contaminants are distributed. Lab results can be hard to understand. If possible, find someone who can help interpret them.

Assessing Environmental Regeneration

The impact of your remediation work does not end with the reduction of a pollutant's concentration. The health of an ecosystem in the days, weeks, and years following an installation also provides invaluable insights into the efficacy of your remediation efforts as well as how to enhance future designs. How have the plant, animal, and fungal communities responded to the installation? Have old inhabitants returned to rebuild their nests or has a new cast of characters taken their place? Are these new inhabitants friends or foes to the surrounding ecology? Are they performing a remediative role that you didn't anticipate or were unable to offer? Are the plants and fungi that you intentionally introduced establishing well or do they need additional support that was not originally planned for? All of these questions and more will help lead to the further refinement of your awareness of Nature's regenerative patterns and the ability to apply those lessons in future designs.

The Facets of Fungal Remediation

With the preceeding skills and concepts covered, the rest of the chapter now explores the details of how fungi remediate pollutants and how humans can work with those capacities most effectively.

Microbial Filtration

Coating our food, lining our stomachs, and filling every breath we take, the bacteria, protazoa, and molds of Earth have co-evolved with humans to feed on our byproducts. For humans with fully functioning immune systems, most microbes tend to have little impact on one's health. Generally, it is only when one's immune system is compromised or unnaturally high concentrations of certain microbes flourish that microbial infections occur. In these instances, many pathogens can cause negative impacts on humans. Some of the more tenacious species are listed to the side.

Common Microbial Pathogens

Bacillus spp.
Candida albicans
Escherichia coli
Listeria monocytogenes
Mycobacterium tuberculosis
Plasmodium falciparum
Pseudomonas aeruginosa
Pseudomonas fluorescens
Staphylococcus aureus
Streptococcus pneumoniae
Streptococcus pyogenes

Under controlled conditions, many fungal species have been shown to defend against, neutralize, kill, and/or consume the listed microbes. If a flowing water systems hosts a large population of these infectious microbes (often due to the mismanagement of sewage or animal wastes), fungal mycelium can be placed in the path of the water to filter the microbes and enhance the health of the environment. A singular study on this practice has shown that the tenacious and stress-tolerant mycelium of King Stropharia can be quite effective at filtering *E. coli.*[11]

Mycelial filtration designs often need to be somewhat site-specific in order to ensure that an installation will be effective for an extended period of time. Semi-annual maintainance and substrate replacement will likely be required to ensure that the filter does not lose its structural integrity due to mycelial degradation.

A two-tiered microbial filtration system, designed by the author, being installed in western Massachusettes. The target pollutant was effluent overflowing from an antiquated septic system.

Heavy Metal Mitigation

Of the 118 elements on the periodic table, 53 are considered "heavy metals": elements with metallic properties and a specific density higher than 5 grams per cubic centimeter. For the remeditator, a handful of these elements are of significant concern due to their common presence in industrial waste streams and their detrimental impacts on soil, plant, and animal health. These include arsenic, cadmium, cesium, chromium, lead, mercury, nickel, and zinc. Some of these elements are beneficial to living organisms in small concentrations but act as toxins when their concentration is above a certain amount. Cadmium, lead, and mercury serve no biological function and are always toxic.[12]

Heavy metals are found in rocks, soil systems, and bedrock. Through the erosion of these substances or the eruption of volcanos, these elements are naturally released into the environment in low concentrations, where they tend to have a minimal impact. Conversely, in areas affected by industrial ore extraction and processing, or waste deposition (e.g. landfills and roadsides), toxic concentrations of these elements arise, leading to an array of negative consequences in the surrounding environment. Agrochemical fertilizers, sewage sludge, pesticides, metal mining, smelting, and oil and gas operations are some of the main sources of heavy metal pollution.

Upon entering a soil environment, many heavy metal ions become bound to clay particles, humus, or other ligands within the first few minutes and hours. Some of these metals may become bound into relatively stable forms that do not pose an immediate threat to living organisms. Other metals may remain unbound, floating in the environment with varying degrees of bioavailability, mobility, and toxicity. Over time, the exchange sites on clay and humic substances will become in-

creasing bound (saturated) with these metals, lowering the CEC of the soil and ultimately affecting the reactions with which these compounds will undergo in a remediation strategy.

Once bound in the soil, heavy metals can persist for thousands of years. As pure elements, metals cannot be "broken down" like chemicals or transformed into other, safer elements. A mercury ion will always be a mercury ion and zinc will always be zinc. Humans can only transmute one element to another through nuclear fission. In order to remediate a heavy metal spill, metals must either be moved out of a soil or water system or bound to other elements within the system to form relatively safe and stable compounds.

If left untreated, high concentrations of heavy metals can cause numerous negative impacts on plants, animals, fungi, and whole ecosystems. This is often due to the heavy metal replacing an essential element during the production or functioning of enzymes in an organism. For example, lead can replace calcium, zinc, and iron during various bodily processes, leading to enzyme pathway malfunction, overall degeneration, and mineral deficiency features in the individual. Heavy metals interfere with cell membranes by limiting the ability of nutrients to move in and out of cells. They can also cause oxidative tissue damage in tissues, leading to nucleic acid mutations and ultimately cancer.[13]

Heavy metal pollution can come from a variety of sources. Fossil fuel combustion and the clouds that billow from industrial smoke stacks carry heavy metals downwind from industrial centers. These metals later enter pristine environments where they rain down on the soil surface and percolate into the subsurface environment and water table during rain events. Widespread blankets of heavy metals like these are not easy to remediate due to their large coverage area. One option for mitigating this issue is to validate the presence of these heavy metals through lichen sampling, report these findings to the EPA and local media, and form an awareness building campaign calling for the polluting to stop. Remediating heavy metals with fungi is most effective when applied to a concentrated stream of pollution, such as that released by the mining, smelting, electroplating, sewage disposal, and fossil fuel extraction industries, or by the application of agrochemical fertilizers and pesticides. Fungi are quite effective in these instances and help reduce the level of these pollutants by adsorbing, solubilizing, and translocating the heavy metals found in soil and water systems.

Mycosorption

The mycelium of many fungal species can naturally bind up (sorb) various heavy metals via an ion exchange mechanism on the mycelial surface. Once the metal ions bind to the mycelial surface, they are generally chelated, adsorped, crystallized, precipitated, entraped in the polysaccharide material of fungal cell wall, and ultimately diffused through the cell wall and membrane. Reactive sites on the tissue surface where sorbing initiates may include amino, carbonyl, carboxyl, hydroxyl, imidazole, imino, phosphate, sulfate, sulfonate, sulfydryl, thioether, and/or other moeities. Experimentation has shown that modifying the mycelium's tissue chemistry through chemical or thermal treatments can increase the sorbency of some species. Dead mycelium can even be effective, decreasing the challenge of designing systems that cater to the needs of a living organism. Other factors that can influence sorbtion include the type, ionic form, and concentration of the heavy metals as well as the functional site on the fungal tissue, the ambient pH and temperature, and the presence of other ions.

The application of mycosorbency in remediation design is most effective in heavy metal polluted water. Simply put, when metal contaminated water passes by the mycelium of the appropriate fungal species, the metals may sorb to the mycelial surface. The metal containing mycelium can then be removed from the water system and treated to reclaim or dispose of the metals. This concept is open to interpretation and can be applied in numerous ways. The most important consideration is that one must combine the proper fungal species and mycelial pre-treatment with the targeted ion. If the contaminated water contains several metals, a series of mycelial nets—each comprised of their own species or perhaps as a "mycoalloy" of several species—may be required to capture the various elements.

Fungal sorbtion does not necessarily require the use of a filter-like system. Bricks of mycelium can also be dragged through the contaminated water to sorb the metals during their movement.

Once the metals have sorbed to the fungus, the mycelium brick can be removed from the water and the metals extracted from the tissue to be recycled. In 2014, the Finnish company VTT Technical developed a method of mycosorbtion that was able to salvage 80% of the gold produced through the processing of old cell phones and other electronic waste. According to Singh, mycosorption rates can be intensified in the presence of a magnetic field, suggesting a synthesis with liquid culture practices.[14]

Solubilization

Being hydrophobic and insoluble, many metal ions and compounds do not readily dissolve in water. Insoluble heavy metals do not move through or out of soil systems readily, leading to their long-term persistence and toxic effects. The living mycelium of many soil-dwelling fungal species can increase the solubility of metals and/or immobilize these elements by producing various metabolites that cause reduction, methylation, or dealkylation reactions with the metals. These substances include:

- **Organic acids:** Negatively-charged organic acids produced by fungi (e.g. citric and oxalic acid) form complexes with positively-charged metal cations. Metal citrates are generally highly mobile while most oxalates tend to be immobile complexes. The oxalates of sodium, aluminum, potassium, lithium, and iron are exceptions as they are soluble complexes. Numerous saprotrophic, mycorrhizal, and lichenicolous fungi produce oxalates.
- **Siderophores:** Bacteria and fungi produce a variety of low-molecular-weight ligands that chelate and solubilize environmental iron (Fe[III]) for their own metabolism. These ligands are known as siderophores; the most common fungal siderophore is ferrichrome.[15] Siderophores also bind to magnesium, manganese, chromium(III), gallium(III), and plutonium(IV).
- **Other compounds:** Many other non-specific metal-binding compounds are produced by fungi, each with their own effect on metal ions. Some are released into the environment, while others (e.g. alcohols and large polysaccharides) remain on the surface of the fungal tissue. Arbuscular mycorrhizal fungi release metal chelating agents such as glomalin, metallothionien, and phytochelatin, which also help increase the immobilization of heavy metals in soils.[16]

Oxalic acid can also bind up calcium ions, which can be toxic when found in excess. Calcium oxalate crystals can be often found around free-living hyphae and mycorrhizal roots.

These metal solubilizing capabilities are best utilized in contaminated soil systems through the introduction of mycorrhizal fungi that have been shown to produce the above compounds. Similarly, mycorrhizal species that are present in the contamination zone may have developed adaptive strategies to deal with the contaminant. For instance, it has been shown that the spores of arbuscular mycorrhizal species isolated from zinc-polluted soils have a higher germination rate when exposed to high concentrations of zinc than the spores of similar species isolated from non-contaminated sites.[17] These locally adapted species/strains can be sampled and amplified through the cultivation practices described in Chapter 9 and subsequently applied as inoculum in the contamination zone, thereby increasing the population of the metal-tolerant strain.

Translocation and Mycoaccumulation

Many decomposing and mycorrhizal fungi have demonstrated the incredible ability to remove heavy metal ions and radioactive isotopes out of their environment by drawing the elements into their mycelial networks. These ions may then be channeled through the network and into fruiting bodies where they accumulate and, in effect, purge the soil of these deleterious toxins. This cleansing function is offered by an array of species from a variety of genera. As with the metal-solubilizing mycorrhizal fungi, metal-accumulating ectomycorrhizal fungi can be collected from contamination sites, amplified using the techniques outlined in Chapter 9, and inoculated back into the landscape in companionship with symbiotic plant species and microbes.

However, where very large areas of land are concerned, such inoculation strategies may prove challenging. Mycorrhizal inoculation techniques are not guaranteed to form symbioses in every

One study from mining sites in Australia found Acaulospora *AM to be the most abundant genus.* Glomus *species were present in unusually low concentrations.*

installation. Of those that do establish, the slow rate of mycoaccumulation may require years, decades, or longer for the fungi to pull all of the contaminants out of the soil and into the annual crops of mushrooms. Further, these metal-laden mushrooms must then be harvested and removed from the environment and either "mined" for their metals or disposed of as a form of toxic waste. If the mushroms are left on site, the metals they have acculumated will remain in the ecosystem after the mushroom decomposes. These toxic mushrooms may even incur greater impacts if they are consumed by animals. For example, deer are known to eat radioactive mushrooms in the impact zone outside of Chernobyl and later develop cancer as a result.[18] Such barriers to successful mycoaccumulation strategies must be accounted for during initial design stages.

Additional Suggestions for Heavy Metal Remediation

In addition to the techniques outlined above, several other practices can be applied to create robust strategies for addressing heavy metals.

- **Biostimulation:** The phosphates found in compost can raise metal adsorption and precipitation rates. In other words, adding compost to contaminated soil may help reduce the availability of heavy metals.[19] Also, poking holes in the ground with rebar and filling them with actively aerated remediative compost tea will increase aeration in the site and inocualate the ground with beneficial, remediative microbes.
- **Adjusting pH:** The pH of soil significantly influences the mobility of many heavy metal cations. At low pH, metal-carbonate complexes tend to dissolve, thereby releasing heavy metals into the soil and ground water metals as free ions or as soluble organometals. By raising the soil pH with the addition of lime, the solubility of aluminum, iron, magnesium, lead, cadmium, and other metals can decrease as they tend to form insoluble mineral phosphates and carbonates.
- **Chitosan:** This commercial product carries a free amine functional group that readily binds to heavy metal cations. Chitosan is water soluble, biodegradable (it is made from modified shrimp shells), and reportedly does not hamper plant growth or the establishment of arbuscular mycorrhizae.[20]

Difficulties in Remediating Heavy Metals

Beyond the variables discussed so far, a challenging question that looms over any metal remediation strategy is how long an installation's effectiveness will hold. As environmental, climatic, and soil conditions change over time, immobilization strategies may prove untenable as bonds break in metal complexes and the mobility of a metal increases. Very little is known about how long metals are even sequestered in the soil.[21]

Such reversal in solubility is known to occur with pyromorphite ($Pb_5[PO_4]_3Cl$), a relatively stable compound that many bioremediators attempt to create as a means for treating lead-contaminated soils. Generally, a phosphorus source (such as fish bones or chicken manure) is added to soils to combine with the lead, forming pyromorphite. However, this compound has been shown to be later broken into its constituents by common soil-dwelling, phosphate-solubilizing fungi, such as *Aspergillus niger*. Plants grown with pyromorphite as their only phosphorus source will accumulate both phosphorus and lead into their tissue.[22] While this unfortunate news does not offer an alternative method for easily treating lead, it does highlight the need for designers to think ecosystemically and long-term in regards to the species that may come after a remediation project is implemented and what impact these or other factors may have on a given installation.

What Do You Do With Heavy Metal Filled Mushrooms?

Any mushrooms harvested from a site contamined with heavy metals should be assumed to harbor metals and be unfit for consumption. These metal-laden fruit bodies must be treated off site to effectively reduce the overall concentration of the metal in the treatment area. Industrial remediation practices may be able to employ controlled incineration methods that can retain metals in the

Sources, Forms, and Habits of Heavy Metals

Arsenic (As)

High levels of arsenic consumption can lead to headaches, diarrhea, confusion, and, in extreme cases, vitamin A deficiency, and night blindness. Arsenic is usually found as either arsenate (As[V], [AsO_4^{-3}]), or as arsenite (As[III], [AsO_2^-]), with the latter having a much higher acute toxicity. In aerobic environments, As(V) predominates and arsenic mobility is low. In anaerobic or high pH environments, As(III) predominates. As(III) is highly soluble and prone to leaching. Arsenite is toxic to humans but can be converted to arsenate via bioremediation. It is used in pesticides, herbicides, pharmaceuticals, pyrotechnics, semiconductors, pressure-treated lumber, and in the insecticide applied in orchards and cotton fields.

Cadmium (Cd)

Cadmium is one of the most prevalent heavy metal poisons. In the soil matrix, cadmium may be adsorbed by clay minerals, carbonates, or hydrous oxides of iron and manganese, or precipitated as cadmium carbonate, hydroxide, or phosphate. In acidic conditions cadmium mobility increases as exchange sites are consumed by H^+ ions. In soil with a pH over 6, cadmium is adsorbed by the soil's available cation exchange sites or is precipitated. Cadmium can also form soluble complexes with inorganic and organic ligands, particularly Cl^-, all of which increase the mobility of cadmium in soils. It is commonly released during the burning of fossil fuels and municipal wastes and in the production of iron, steel, phosphate fertilizers, and refined zinc.

Cesium (Cs)

Cesium can form 39 different isotopes, many of which are radioactive. Cs-135 is one of longest-lived products of uranium fission in nuclear reactors, while Cs-137 is responsible for much of the radioactivity in the fallout area surrounding Chernobyl and in areas in Japan and North America affected by the Fukushima reactor meltdown of 2011. Like other radioactive elements, such as plutonium and uranium, cesium causes mutations and cancer in living organisms by emiting gamma radiation that interferes with cellular processes.

Chromium (Cr)

Chromium normally occurs in the form of inorganic ions as Cr(III) and Cr(VI). Under aerobic conditions, chromium exists in the (VI) state, usually as chromate (CrO_4^{-2}). However, if chromate is under even slightly acidic conditions this oxyanion will take on a proton and become $HCrO_4^-$. The oxyanions of Cr(VI) are highly soluble in water. Under anaerobic conditions, chromium exists in the (III) state. Cr(VI) is toxic and a suspected carcinogen, wheras Cr(III) is much less toxic, and even acts as a trace nutrient. Chromium pollution is produced during chrome plating, leather tanning, brick making, wood preserving, and in the production of steel, dyes, and pigments.

Lead (Pb)

Lead is often found as Pb(II), as oxides and hydroxides, and in lead-metal oxyanion complexes. Above a pH of 6, lead either adsorbs to soil surfaces or forms lead carbonate ($PbCO_3$). It is also immobilized in the presence of clays, phosphates, sulfates, carbonates, hydroxides, and organic matter. Under anaerobic conditions, a volatile organolead (tetramethyl lead) can be formed due to microbial activity. Lead was commonly used in many construction materials, fuels, and paints until it was largely banned in many countries in 1978. Leaking underground storage tanks (LUSTs) at old gas stations often spill lead into the environment. Lead significantly affects the brain, heart, kidneys, intestines, bones, nervous system, and reproductive system of humans. Children are especially vulnerable to its effects.

Mercury (Hg)

Mercury is typically encountered in its elemental form (Hg), as mercurous ions (Hg_2^{+2}), or as mercuric ions (Hg^{+2}). Clays, oxides, and organics absorb the mercurous and mercuric cations, with adsorption rates increasing in higher pH soils. Mercury ions are also immobilized by forming precipitates with chloride, phosphate, carbonate, and hydroxide—at the mercury concentrations

A Note on Radiation

While fungi can uptake and translocate radioactive atoms, they cannot "destroy radiation." Radioactive ions, such as Cesium-137, are pure elements that cannot be readily transmuted into another element or non-radioactive ion. Radioactive compounds are hazardous because they emit gamma radiation: high frequency photons that interfere with our DNA and cause mutations. When fungi uptake radioactive ions, the fungal tissue will emit this gamma radiation for as long as the ions are in its tissue. Thus, mushrooms harvested from a nuclear fallout zone may help remove radioactive atoms from the soil, but they are not destroying these atoms nor reducing their gamma radiation output.

typically found in soil, only the phosphate precipitate is stable. As soil pH lowers, mercuric ions form complexes with soluble organic matter, chlorides, and hydroxides, increasing the mercury's mobility. In anaerobic conditions, mercury compounds can degrade to elemental mercury, which in turn can be readily converted to methyl and ethyl mercury by biotic and abiotic processes. These two compounds are the most toxic forms of mercury as they are volatile and soluble in water and also cause significant neurological effects in adults, children, and unborn fetuses. Mercury is primarily used in the production of industrial chemicals and electrical and electronic applications. Many household products and tooth fillings contain mercury.

Selenium (Se)

Selenium exists in the soil in four states: elemental selenium (Se), selenide (Se^{2}), selenite (SeO_3^{2}), and selenate (SeO_4^{2}). The concentration and form of selenium in soil is governed by soil's pH, redox potential, and overall composition. Selenate is the dominant form in high pH soils. In acidic soils, selenite is the primary state. Similar to other anionic species, selenium is more mobile at higher pH levels. Under anaerobic conditions, selenium is converted to its elemental form, while organic forms of selenium can undergo biomethylation forming volatile selenides.

Other harmful metals include aluminum (Al), antimony (Sb), barium (Ba), berryllium (Be), cobalt (Co), copper (Cu), lithium (Li), manganese (Mn), molybdenum (Mo), nickel (Ni), iron (Fe), silver (Ag), thallium (Tl), tin (Sn), uranium (U), vanadium (V), and zinc (Zn). Some of these metals have also been investigated for their ability to be influenced by fungi. Little is known about the removal of radium, thorium, strontium, and neodymium by filamentous fungi.

ash of burned mushrooms for later recycling or disposal. Unfortunately, this process is not easy to safely replicate by remediators with small budgets. The following are some of the best strategies I am currently aware of for answering this challenging question:

- Ship the mushooms to a landfill or other toxic waste disposal site. Be aware that many waste disposal sites may simply incinerate the mushrooms, sending the metals back into the air in the smoke.
- Where off-site disposal is not an option, a sacrifice zone can be designated for disposal of the mushrooms. Metal tolerant, non-fruit bearing trees can then be planted over these sites to guard against the growth of other plants that may accumulate the metals into their tissue and fruit.
- Worm castings can be applied to metal contaminated soils to potentially bind up the cations (vermi-remediation).
- Place the mushrooms in a constructued wetland. In these environments, anaerobic bacteria can convert sulfates ($-S_2O_4$) to sulfides ($-SO^{2-}$), which have a strong affinity for the divalent (2^{+}) heavy metal ions being treated. Above a pH of 5, metal sulfides form that are very stable and insoluble, enabling them to stay in the bottom of the wetland for years, if not centuries. This same process is used industrially in what are known as "passive biochemical reactors."[23]
- In the book *Mycoremediation*, Singh discusses several elaborate methods for removing metals sorbed to mycelium so as to reuse the mycelium for further remediation efforts and/or to reclaim and recycle the metals.[24]

Chemical Degradation

The fungi are unique in their digestive capacities for they alone are able to break down some of the most persistant compounds found in Nature or produced by humans. This remarkable trait holds great potential for addressing the intentional and accidental buildup of toxins in the environment, leading to a significant amount of research into the field over the decades. Ultimately, it seems that the limitations of chemical remediation by fungi are not that mysterious, but merely an outcome of

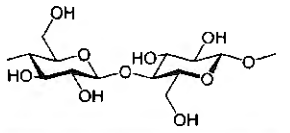
the pollutant's chemical structure. Many of these compounds share a structural similarity to lignin, one of Nature's most rot-resistant compounds and a molecule that only fungi are known to degrade. To best unpack this concept, a thorough review of fungal wood decay is needed.

Lignin and the Plant Cell

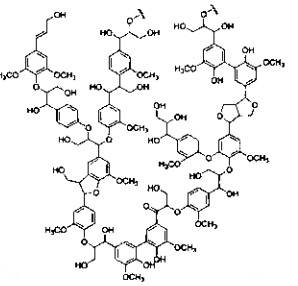
Similar to fungi, plant cells have an exterior wall that adds rigidity and structure to the tissue of the plant. Unlike fungi, however, the plant cell wall does not contain chitin. Rather, they are more like a fluid matrix composed of cellulose fibrils, hemicellulose, and proteins all glued together with a large amount of pectin. The ratio of these components varies between cell types, tissues, and plant species, but an approximate dry weight measurement of a plant cell wall is 30% cellulose, 25% hemicellulose, 35% pectin, and 10% protein. Woody plants also produce a multi-layered secondary cell wall that contains lignin.

- **Cellulose:** Cellulose is a relatively simple polysaccharide comprised of a long chain of glucose sugars. When multiple cellulose chains bond to each other in parallel they create *microfibrils*, which can be up to 3 nanometers in diameter. These microfibrils are embedded in the cell wall matrix where they act as the main structural material of the cell's primary wall.
- **Hemicelluloses:** Hemicellulose compounds are comprised of different combinations of neutral and acidic polysaccharides. There are several types of hemicellulose structures, all of which enhance the structural integrity of the cell wall. These include xylan, glucuronoxylan, arabinoxylan, glucomannan, and xyloglucan; each are comprised of different kinds of sugar monomers.
- **Lignins:** Compared to the relatively simple structure of cellulose, lignin is a complex, irregular, three-dimensional compound. Like hemicellulose, there are numerous forms of lignin, each comprised of a different combination of basic units. However, the base units of lignin are not sugars but three modified forms of cinnamyl alcohol: the phenylpropanes coumaryl alcohol, coniferyl alcohol, and sinapyl alcohol. Through an unknown process (potentially oxidation) these three alcohols randomly bond together during lignin synthesis to form a wide number of structures, all of which are considered a form of lignin.

  Lignin structures vary from plant to plant and even between different parts of a given plant, though all are highly irregular and filled with many phenolic rings and strong C–O–C and C–C bonds. In the secondary cell wall of plants, lignin bonds with hemicellulose and surrounds cellulose microfibrils, providing additional strength and rigidity to the plant tissue. Pure lignin is a rather large compound (10^5 Da or more) and is nearly impossible to isolate from plant matter. Thus, synthetic lignin-like compounds (e.g. dehydrogenative polymerizate [DHP]) have been developed to study the process of lignin degradation under controlled conditions. Not many fungi can degrade lignin; of those that can, lignin does not seem to be their primary carbon souce. Rather, these fungi likely degrade lignin in search of sugar-rich cellulose and hemicelluloses.



A segment of a cellulose chain.



A form of lignin. Note the abundance of ringed structures.

It is important to note that the constituents of a plant cell wall are all intimately mixed. So rather than describing fungal digestion as the consumption of discrete compounds it is better to think of the following processes as the degradation of lignocellulosic and/or lignoprotein complexes.

Wood Rot Revisited

Reflecting the range of plant compositions and forms, decomposing fungi have developed several ecological niches that target the different parts and types of plants found in a given habitat, climate, and state of decay. As the degradation of woody plants has numerous implications for fungal biology and the overall ecology of an ecosystem, mycologists categorize wood-decomposing fungi into one of three groups to describe a given species' niche and, ultimately, their ecological role.

Example Brown Rotters

Fomitopsis officinalis
Fomitopsis pinicola
Gloeophyllum trabeum
Hypsizygus ulmarius
Laetiporus conifericola
Laetiporus sulphuresus
Meruliporia incrassata
Morchella angusticeps?
Piptoporus betulinus
Schizophyllum commune
Serpula himantiodes
Serpula lacrymans
Sparassis crispa

Example White Rotters

Agaricus bernardii
Agaricus brasiliensis
Agrocybe aegerita
Armillaria spp.
Bjerkandera adusta
Bjerkandera spp.
Chlorophyllum rachodes
Chrysonilia sitophila
Chrysosporium lignorum
Coprinus comatus
Cyathus bulleri
Cyathus spp.
Dichomitus squalens
Flammulina velutipes
Fomes fomentarius
Funalia trogii
Ganoderma applanatum
Ganoderma lucidum
Grifola frondosa
Hericium abietis
Hericium erinaceus
Hypholoma capnoides
Hypholoma frowardii
Hypholoma sublaterium
Inonotus obliquus
Irpex lacteus
Lentinula edodes
Merulius tremellosus
Macrolepiota procera
Phanerochaete chrysosporium
Phlebia radiata
Pholiota nameko
Pleurotus eryngii
P. flavido-alba
P. ostreatus
P. sajor-caju
Psilocybe cubensis
Psilocybe cyanescens
Pycnoporus cinnabarinus
Schizophyllum commune
Stropharia ruggoso-annulata
Trametes hirsuta
Trametes versicolor

- **Brown rot:** Brown rotters primarily digest the cellulose and hemicellulose in trees, leaving beind a modified form of lignin. Brown rotters include several species of Basidiomycetes, most of which are common on softwood trees. Compared to white rotters, they have not been heavily researched for their chemical degradation capacities.
- **White rot:** White rot fungi are the most thoroughly researched remediative species due to their unique ability to degrade lignin. They have been the focus of at least 30% of all mycoremediation research.[25]
- **Soft rot:** A number of Ascomycetes and micro fungi can slowly degrade tree species that are too hot, cold, or wet for brown rot and white rot species. Despite these unique adaptations, along with the ability of some soft rotters to degrade lignin, these species have not been extensively studied for their remediative capacities.

Enzymatic Combustion: An Overview of White Rot

The development of lignin was a masterstroke in the evolution of defense mechanisms. With their large size, strong bonds, and wide variety of forms, lignins are the perfect barrier to the compound-specific enzymes that microbes and fungi typically use to digest their food. Lignin's high concentration of phenolic rings also defends plant tissues as their water-repellent nature blocks the penetration of enzymes, which tend to be watersoluble. Despite these barriers to entry, white rot fungi long ago developed an ingenious, back door strategy for dissasembling lignins that does not rely on the direct application of an enzyme. For these species, the trick to cracking lignin open is to create small ions that enter lignin structures and cause an oxidative chain reaction that disassembles the molecule piece-by-piece.

Oxidation is commonly seen in the rusting of metals, the browning of cut apples, and the development of a patina on copper. Technically, oxidation is the loss of an electron due to the interaction of two or more substances, which results in the modification of the substances involved and/or the creation of novel byproducts, such as a patina or rust. Many forms of oxidation are not commonly witnessed. Oxidation in bodily tissue can cause negative effects. The oxidation of lignin is also somewhat invisible as it does not result in a color change of lignin but in the slow degradation of the entire compound.

Most mycologists agree that in order to oxidize lignin, fungi produce several compounds that react with each other to form small, positively-charged byproducts known as *free radicals*. These free radicals are what then penetrate into lignin structures, where they essentially bounce around inside the molecule, randomly stealing electrons from lignin's phenol rings and side chains, until the components of the lignin structure fall off and the entire compound is left disassembled.

These initial compounds are H_2O_2 and a fungal enzyme, which, depending on the fungus, may be lignin peroxidase (LiP), manganese peroxidase (MnP), and/or laccase. When one of these three enzymes interacts with H_2O_2, the latter is split into H_2O and free radical oxygen atoms. After these radicals enter lignin, the once tightly bound compound is left "opened up" and vulnerable to the further degrading effects of water and oxygen.[26] The various components that are broken off of the lignin structure may also be further degraded by fungal laccase or another enzyme. The end result is the complete disassembly of lignin into smaller parts that may be further mineralized into carbon dioxide, ammonia, chlorides, and water.

A key feature of this process is that these free radicals are non-specific in their effect, allowing them to degrade all forms of lignin as well as many persistant industrial pollutants.[27] These free radicals are the chemical "keys" that fungi use to unlock lignin and many industrial toxins.[28] This incredible, uncontrolled, and energy-releasing process is known as *enzymatic combustion*, emphasizing the destructive potential of this unique survival tactic.

Laccase, LiP, and MnP are all found in various forms, amounts, and ratios in different white rot species, a fact that has lead some researchers to propose dividing white rot species into three major categories based on which compounds they produce:

- The lignin–manganese peroxidase group (e.g. *Phanerochaete chrysosporium* and *Phlebia radiata*).
- The manganese peroxidase–laccase group (e.g. *Dichomitus squalens* and *Rigidoporus lignosus*).
- The lignin peroxidase–laccase group (e.g. *Phlebia ochraceofulva* and *Junghuhnia separabilima*).

Some fungi do not fit neatly into these three groups. For instance, Turkey Tail synthesizes all three of these enzymes. The production levels of these enzymes can also be influenced by the fungus' substate. Reishi will produce MnP when grown on poplar wood but not when pine wood is its primary substrate. The variable delignifiying characterics of a given species or strain directly influence that fungus' ability to degrade chemical pollutants and also helps to explain why some white rot species can degrade certain compounds that others cannot. Further, each species may produce a fairly unique "suite" of enzymes that work synergistically and in a specific sequence, often with greater efficacy than when the constituent enzymes are applied in isolation.[29]

In addition to LiPs, MnPs, and laccases, white rot fungi also produce low-molecular-weight oxidants (mediators) that create the H_2O_2 required for delignification. The specific mediator used varies by fungal species; common mediators include glucose-1-oxidase, pyranose-2-oxidase, glyoxal oxidase, methanol oxidase, and veratryl alcohol oxidase. All of these enzymes seem to produce H_2O_2 through the reduction of molecular oxygen. Glyoxal oxidase works to create H_2O_2 by transfering electrons from low-molecular-weight aldehydes (e.g. glyoxal and glycoaldehyde) to O_2.

White rot is not a fast process. Under ideal conditions, Phanerochaete chrysosporium *can only degrade one gram of lignin per gram of fungus (dry weight) in 48 hours, producing about 70% CO^2 and 30% low-molecular-weight water-soluble compounds.*

This oxygen does not come from the air, but as peroxide (O_2^{2-}) provided by another food source such as cellulose, hemicellulose, or, in the lab, pure glucose. Without a substrate that will provide these peroxide anions, the fungus will not be able to produce H_2O_2 and the rest of the lignin (or chemical) breakdown process will not occur.[30] Delignification seems to be initiated as a secondary metabolic process when the nutrients in primary substrates are depleted (e.g. nitrogen). Taking these last two sentences into consideration, a general approach to remediation strategies addressing chemical compounds should be to always include extra, simpler substrates (e.g. straw) when inoculating contaminated substances. As with all of the enzyme-dependent actions of fungi, proper nutrition and substrate formulation is necessary for the most effective chemical remediation strategies.

Lignin Peroxidase (LiP)

First discovered in 1983 in *Phanerochaete chrysosporium*, LiP has been thoroughly studied for its three step, one-electron oxidation of lignin. Most (but not all) white rot species produce LiP. As many as 15 forms (isozymes) of LiP have been isolated.

Technical Details

LiP is a highly glycosylated heme-containing peroxidase with an unusually high redox potential. Its molecular weight is around 40 kDa and, depending on the isozyme, it is roughly 340 amino acids in length. Its three-dimensional crystal structure is 2–2.5 Å in size and it resembles cytochrome c oxidase. LiP can oxidize methoxyl substituents on non-phenolic aromatic rings by the generation of cation radicals that undergo further reactions. LiPs can oxidize the cleavage of β–O–4 linkages, $C\alpha$–$C\beta$ linkages, and other bonds in lignin. They are also involved in side-chain cleavages, demethoxylations, ring-opening reactions, benzyl alcohol oxidations, and oxidative dechlorination of lignin. LiP has been shown to be most effective at a pH below 3.0. However, it is very unstable in such an acidic environment. Some fungi produce higher levels of LiP when nitrogen levels are low. Certain LiPs can oxidize manganese.[31]

Veratryl alcohol (VA) seems to act as a cofactor that enhances LiP activity, potentially by protecting LiP from the inactivation effects of excess H_2O_2. LiP is unique in its ability to produce radical cations from the one-electron oxidation of non-phenolic aromatic compounds such as VA or 1,4-dimethoxybenzene (DMB), which have redox potentials beyond the reach of either MnP or laccase. Radical cations of VA or DMB are able to act as non-specific redox mediators, with the effect being that both the substrate range and redox capacity of LiP can be extended. VA is some-

Several other remediative compounds have also been identified. These include tyrosinases, versatile peroxidases, coprinopsis cinerea peroxidase, dye-decolorizing peroxidases, caldariomyces fumago haem–thiolate chloroperoxidase, haem–thiolate peroxygenases, cytochrome P450 monooxygenases, phenol 2-monooxygenases, nitroreductases, quinone reductases, reductive dehalogenases, and various transferases. Other important remediation enzymes appear to be lactases, methylases, and quinones. These compounds are not as heavily researched, but they seem to function somewhat similarly to the enzymes detailed here.

times added to cultures to stimulate ligninolysis. Aryl-alcohol dehydrogenase also appears to be important for the stability of LiP.

Magnesium Peroxidase (MnP)

MnP is a glycosylated heme-containing enzyme. Its effect on lignin is produced when H_2O_2 oxidizes Mn(II) (a common element in wood and soil) to Mn(III) through a series of steps. This Mn(III) is very unstable and quickly chelates with organic acids (such as malonate or oxalate), producing a chelation product that goes on to penetrate and oxidize lignin or other phenolic substances. Nitrogen-deficient conditions seem to favor the production of MnP in some fungi while excess H_2O_2 can interfere with the effects of MnP. MnP is produced by most white rot species, including soil litter species in the Strophariaceae and Tricholomataceae. It appears to be more common than LiP.

Technical Details

The molecular weight of MnP ranges between 38 and 62.5 kDa; the molecular weight of the most purified MnP is 45 kDa. Over 10 isozymes have been detected, with an average length being around 360 amino acids. MnP has a lower redox potential than LiP. Interestingly, MnP has been shown to oxidize some aromatics without the intervention of manganese ions.[32]

Laccases

Laccases are blue oxidases that contain four copper atoms and catalyze the one-electron oxidation of diphenols and aromatic amines (mainly those with a low redox potential) by removing an electron and a proton from a hydroxyl group, forming a free radical. Numerous low-weight, nitrogen-containing mediators seem to assist in this process. Laccases generally seem to work in conjunction with MnP and LiP to degrade lignin. However, *Pycnoporus cinnabarinus* does not produce LiP nor MnP for lignin degradation but only laccase.[33] This rare situation has called into question the generally perceived requirement of LiP or MnP for oxidative delignification. Laccase is not H_2O_2-dependent but rather causes delignification through demethylation of the substrate.

Some laccases can, in the presence of suitable mediators, oxidize Mn(II) to Mn(III), which can, in turn, oxidize other compounds.[34] This mechanism considerably extends the range of compounds and materials that can be oxidized by laccases. Most white rotters produce laccase and it is often the most dominant extracellular enzyme produced in liquid cultures. Turkey Tail and Pearl Oyster mushrooms are good examples of this, both producing an abundance of laccase in liquid media. Laccases are versatile and occur widely in fungi. They regulate morphology, control nutrition, fungal pigmentation, detoxification, pathogenicity, fruit body formation, and sporulation.

Technical Details

The major determinant in whether a compound will or will not be oxidized by laccase seems to be the redox potential differences between the reducing compound and the type I copper in the laccase's active site. This property gives laccase the ability to oxidize a broad range of compounds, so long as the chemical's redox potential is not too high.[35]

There are several forms of laccase, each with a molecular weight of 60–80 kDa. Their optimum pH is generally 3.0–5.7, however some laccases of soil-inhabiting Basidiomycetes have an optimal pH of 7.0. The redox potential of laccase varies as well. Their optimum functioning temperatures are often around 104°F (40°C), but can be as high as 167°F (75°C). Laccase from *Coprinus cinereus* is 2.2 Å in its crystal form. Laccase gene-specific sequences have been detected in brown-rot fungi. Turkey Tail is one of the most efficient laccase-producing fungi.

Soil Fungi vs. Chemicals

Since the initial research into the remediative abilities of *Phanerochaete chrysosporium* decades ago, the majority of studies on mycoremediation have focused on white rot species. However, in recent years a number of studies have shown that, surprisingly, many soil fungi also retain the ability to break down a wide variety of aromatic pollutants such as PCBs, TNT, pesticides, chlorinated phenols, and high-weight PAHs.[36] Some mycorrhizal fungi can even degrade PCBs more effectively than *Phanerochaete chrysosporium*, the "poster fungus" of white rotter remediation.[37]

Trichoderma Mediation

Adding to the many wonders of *Trichoderma* species discussed in Chaper 9, these soil fungi also turn out to be rather potent remediators. *T. harzianum* and *T. viride* can effectively degrade the PAHs pristine, hexadecane, and pyrene (up to 75%),[44] as well as organochlorides similar to those used in the paper industry. *T. harzianum* can degrade many pesticides, including ciliate, glyphosate, DDT, dieldrin, endosulfan, pentachloronitrobenzene, and pentachlorophenol,[45] as well as the herbicide Diuron (60% in soil after 24 hours).[46] These effects may be enhanced when applied in concert with other fungi as the combination of *T. viride*, *Aspergillus carneus*, and *Fusarium oxysporum* has been found to degrade the herbicide trifluralin to over 90% efficiency.[47]

With the plant support that *Trichoderma* species provide (notably *T. harzianum* strain T22), these fungi can also enhance phytoremediation strategies by raising the innate remediation abilities of plants. *T. harzianum* T22 has been shown to increase arsenic uptake in the hyperaccumulating fern *Pteris vittata* by up to 140% compared with nontreated plants. Its combination with the cyanidehyperaccumulating willow (*Salix eriocephala*) may be effective for treating cyanide-polluted soils. It also increases cadmium, lead, manganese, nickel, and zinc uptake in both *P. vittata* and *S. fragilis*.[48]

Many of the studies of remediative soil fungi have worked with mycorrhizal species that were collected from non-contaminated areas, suggesting that their demonstrable remediative traits were not site-specific adaptive strategies but, rather, innate survival tactics. Why these species break down toxic industrial compounds has not been fully resolved. One hypothesis is that these fungi degrade aromatics to liberate nitrogen, phosphorus, and other nutrients that their habitat is otherwise lacking.[38] In my assessment, these remediative soil fungi fall along a blurry spectrum that runs between decomposer and symbiont, likely serving a range of ecological roles, some of which have yet to be detemined.

Arbuscular mycorrhial (AM) species host an array of remediative properties, potentially being able to degrade contaminants such as atrazine, PAHs, DDT, and weathered p,p-DDE in soils,[39] while also helping plants survive in soil containing PAHs.[40] True to the interdependence of nutrient cycles, it may not just be the AM that are remediating these componds but also other soil microbes that are influenced by the AM.[41]

Many ectomycorrhizal (ECM) fungi have shown the ability to degrade the herbicides atrazine and 2,4-dichlorophenoxyacetic acid (2,4-D).[42] However, ECM fungi may not fully degrade pollutants but initiate the decomposition process that is completed by other, free-living microorganisms in the rhizosphere. Thus, combining ECM fungi and bacteria in remediation strategies will help create a healthy biofilm in the mycorrhizosphere that can most effectively coordinate the soil symphony and enhance the health of the environment's biota.[43] This introduction of ECM fungi has therefore been argued to eliminate the common industrial practice of applying toxic co-substrates (e.g. biphenyl) to bioremediation strategies that utilize bacteria and other microbes.

The Cast of Chemical Characters

With delignification explained, the rest of this section details the various types of industrial pollutants that fungi are uniquely able to degrade. Despite their range of sources and effects, the greatest commonality among these compounds is found in the structural features that they share with lignin. It is not by chance that the fungi can degrade so many industrial compounds, but primarily due to the fact that many of the most persistant chemicals contain phenols and biphenyl units that are similar to the alcohols that constitute lignin.

Understanding this core principle will help inform the development of any experimental remediation design. Where an ideal remediative species is not known for a given compound, remediators can compare the chemical structure of the target compound to those found in the categories below. From there, fungi that are known to degrade chemically similar compounds can be identified as potential species to experiment with. This is especially true for compounds that fall into the following two categories, which, as a broad generalization, contain the majority of the compounds that fungi are known to remediate:

- **Aromatics:** Compounds in this group contain multi-atom rings with double bonds, known as aromatic rings or *aromatics*. Six-carbon benzene rings are one of the most common aromatic structural units in compounds remediated by fungi. Many aromatic compounds are only produced by human industries. Like lignin, these artifical aromatic compounds tend to be resistant to degradation, leading to their environmental persistence and impacts. Polycyclic aromatic hydrocarbons (PAHs) and modified aromatics are some of the most toxic compounds that fungi are known to remediate.
- **Non-Aromatics:** Fungi can break down a wide array of chemical compounds that do not contain aromatic rings. For the context of this chapter, however, the term "non-aromatic" refers to a small group of industrial pollutants that do not contain aromatic rings, are highly toxic, and yet are readily degraded by fungi.

Petroleum Hydrocarbons

The petroleum that is pumped out of the ground is not a singular substance, but a blend of hundreds of different low- and high-weight compounds. Through the refinement of this crude, these compounds are separated and, based on their weight and chemical properties, used to make a wide variety of solvents, fuels, asphalts, lubricants, waxes, pesticides, and other products. The various constituents of crude oil are collectively called petroleum hydrocarbons, despite the fact that some of these components contain sulfur, nitrogen, and oxygen.

Due to the complexity of crude oil, soil and water samples taken from an area contaminated with this substance are usually tested for their Total Petroleum Hydrocarbon (TPH) concentration instead of the concentration of the individual compounds. Hanby Field Tests (discussed earlier) are commonly used by petroleum extraction and remediation companies for this purpose. The various petroleum hydrocarbons can be categorized into four weight-based fractions, each with their own remediation requirements.

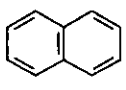
- **Saturates:** These low-weight compounds are not comprised of aromatic rings but saturated carbon chains and rings. They include straight-chain alkanes (normal alkanes), branched alkanes (isoalkanes), and cycloalkanes (naphthenes).
- **Aromatics:** This group includes volatile monoaromatic hydrocarbons (BTEX), PAHs, and aromatic sulfur compounds (thiophenes, dibenzothiophenes).
- **Asphaltenes:** These large molecules disperse in crude oil in a colloidal form. They include phenols, fatty acids, ketones, esters, and porphyrins. Crude oils that contain a large amount of asphaltic compounds never fully degrade.[52]
- **Resins:** Pyridines, quinolones, carbazoles, sulfoxides, amides. These polar molecules contain nitrogen, sulfur, and O_2, and tend to appear as solids dissolved in oil.

Aromatic Compounds

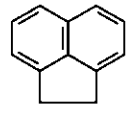
Polycyclic Aromatic Hydrocarbons (PAHs)

There are over 100 PAHs, which, as their name implies, are comprised of two or more aromatic rings made up entirely of hydrogen and carbon. PAHs lack any branching structures; their rings are simply found in linear, angular, or clustered arangements. PAHs are generally water insoluble and thermodynamically stable, with angularly arranged PAHs (e.g. phenanthrene, benzo[*a*]pyrene, and pyrene) being more stable than linear arrangements (e.g. anthracene and benz[*a*]anthracene). PAHs with more than six rings are considered large and are less common than smaller PAHs. Higher weight PAHs are less watersoluble than their smaller relatives, a factor that contributes to the persistence of these 6+ ring PAHs in the environment. Two- and 3-ring PAHs volatize easily and can be degraded by bacteria while 5- and 6-ring structures may bind to clays and other exchange sites in soil where they can persist for years. The U.S. Environmental Protection Agency has identified 16 PAHs as "priority pollutants:"

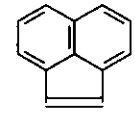
- **2-ring:** Naphthalene
- **3-ring:** Anthracene, phenanthrene, fluorene, acenaphthene, acenaphthylene
- **4-ring:** Fluoranthene, chrysene, pyrene, benzo[*a*]anthracene
- **5-ring:** Benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, dibenzo[*a,h*]anthracene
- **6-ring:** Benzo[*g,h,i*]perylene
- **7-ring:** Indeno[*1,2,3-cd*]pyrene



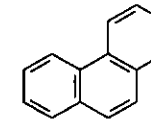
Naphthalene



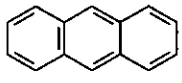
Acenaphthene



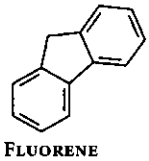
Acenaphthylene



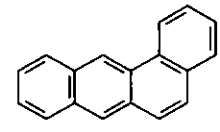
Phenanthrene



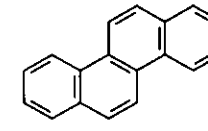
Anthracene



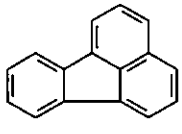
Fluorene



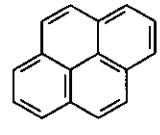
Benzo[a]anthracene



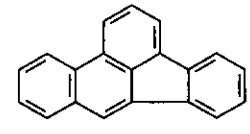
Chrysene



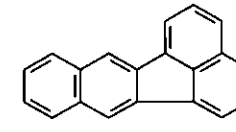
Fluoranthene



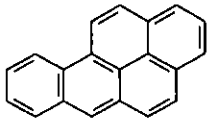
Pyrene



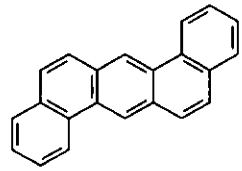
Benzo[b]fluoranthene



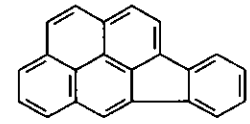
Benzo[k]fluoranthene



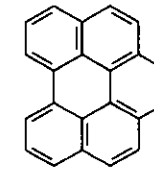
Benzo[a]pyrene



Dibenzo[a,h]anthracene

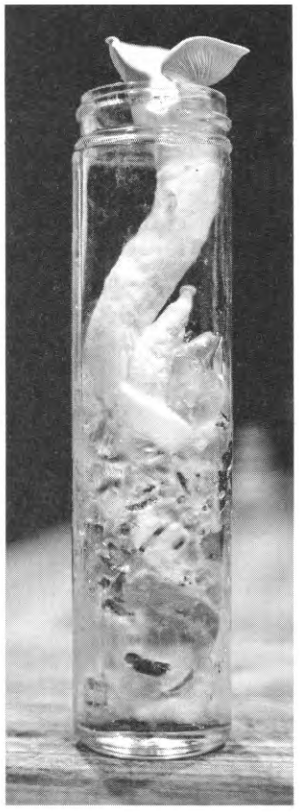


Indeno[1,2,3-cd]pyrene



Benzo[g,h,i]perylene

The generic term persistant organic pollutants (POPs) is often used to describe compounds that contain carbon and are not readily degraded. Likewise, the term volatile organic compounds (VOCs) is used to denote chemicals that contain carbon and have a low boiling point.



Pleurotus ostreatus *fruiting from used cigarette filters. These filters are saturated in PAHs and other toxins that the fungus can digest as a viable nutrient source.*

Sources

PAHs are commonly produced in the burning of organic matter (e.g. fossil fuels, shale oil, or cigarette smoke) as well as in the production of petroleum and coal, the charring of meat products, and in the creosote residue produced by wood-preserving industries.

Environmental Impact

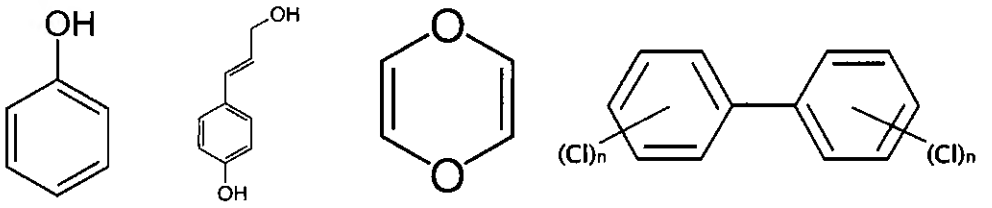
PAHs are one of the most widespread organic pollutants. In urban areas, the total background levels of PAHs can commonly reach 1–5 milligrams per kilogram of soil. Industrial areas are even more polluted, with levels often being 10–20 times higher.[49] PAHs are lipophilic, meaning they are attracted to oils and can absorb into the fats of humans and other animals. Some PAH metabolites also bind to DNA, RNA, and proteins, resulting in various forms of cell damage. They are mutagenic, tumorigenic, and carninogenic. BTEX compounds can cause a decrease in the formation of mycorrhizae. Benzo[*a*]pyrene and naphthalene are two of the most common PAHs in the environment, with the former being commonly found in ciagarette smoke and extensively studied for its highly carcinogenic effects.

The byproducts of PAH degradation by fungi, such as hydroxyl derivatives and quinones, tend to be less toxic than their parent compound(s) and can be fully mineralized to water and carbon dioxide.[50] However, some byproducts are known to be mutagenic and carry their own degree of toxicity.[51] Be careful.

Modified Aromatics

Whereas PAHs are comprised entirely of carbon rings with attached hydrogen atoms, modified aromatics have different elements in their ring features and/or host attached elements, sidechains, or other structures.

- **Substitution:** In substituted aromatics, one or more carbon atoms in an aromatic ring have been replaced by a non-carbon element such as nitrogen or oxygen. The most noteable toxins in this category are dioxins, which contain oxygen atoms in place of carbon in their rings.
- **Attachment:** Aromatics in this group have elements other than carbon and hydrogen attached to their ring structure. Phenol, a central component of lignin, is an aromatic ring with a hydroxyl group (OH^-) attached. When chlorine atoms attach to the dual aromatic structure biphenyl, polychlorinated biphenyl (PCB) is formed. Chlorinated aromatics seem to be especially toxic, being frequently used as pesticides in the form of chlorobenzenes, dichlorophenols (DCPs), trichlorophenols (TCPs), or pentachlorophenols (PCPs). Explosive nitroaromatic compounds, many synthetic dyes, and the endocrine disruptors bisphenol A (BPA) and nonylphenol are also modified aromatics.



Phenol **p-Coumaryl Alcohol** **1,4-Dioxin** **PCB**

Sources

Dioxins have no common use. They are produced as byproducts of paper and pulp bleaching, pesticide manufacturing, waste incineration, and the production of wood preservatives. Dioxins are also released when chlorine-containing items such as PVC plastic, bleached paper, diesel fuel, and coal are burned.

For much of the 20th century, PCBs were frequently used in pesticides, adhesives, fire retardants,

paints, and railroad ties as well as for lubricants and coolants in capacitors, transformers, and other electrical equipment. In the late 1970s their production was banned for most uses in the U.S. and Canada due to the significant health impacts they were associated with. Despite these regulations, PCBs are still released into the environment due to the presence of legacy products in landfills, old buildings, and industrial areas. Some "enclosed" products are still produced with PCBs.

There are over 250 pesticides currently used throughout the world; around 150 are herbicides.[54] Not all of these pesticides contain aromatic rings. The most commonly used pesticides are herbicides, insecticides, and fungicides. Commonly applied pesticides that fungi are known to address include alachlor, aldrin, atrazine, chlordane, DDT, heptachlor, lindane, mirex, 2,4-D, and 2,4,5-T. These last two compounds are mixed in equal parts to make the infamous defoliant Agent Orange.

Over 700,000 tons of synthetic dyes are produced annually for a variety of industries (e.g. textiles, cosmetics, paints, inks, and plastics). Dye-contaminated waste waters are released into the environment in abundant quantities by these industries, often in countries with few environmental protection policies. More than 100,000 synthetic dyes have been discovered; example compounds include Azure B, Congo Red, Disperse Yellow 3, Orange II, and Tropaeolin. Various heavy metals may be released along with these dyes as part of their production.

Nitroaromatics are aromatic rings with one or more nitro functional groups (NO_2) attached. Some are highly explosive. Example compounds include 2,4,6-trinitrotoluene (TNT); 2,4-dinitrotoluene; 2-amino-4,6-dinitrotoluene; 1-chloro-2,4-dinitrobenzene; 2,4-dichloro-1-nitrobenzene; and 1,3-dinitrobenzene. TNT is commonly used in construction and demolition.

Bisphenol A is primarily used in the production of softer plastics, such as those in water bottles and aluminum can lining. When these containers get heated or stressed, BPA can leach into the food and water that they contain. Nonylphenol is used in the production of lubricants, dish detergents, heat stabilizers, emulsifiers, and as an antioxidant for protecting certain polymers.

Environmental Impact

Dioxins are known carcinogens and endocrine disruptors that cause significant developmental effects in animals and children. They are very persistant.

PCBs are among the most widespread contaminants. They are extremely insoluble, chemically unreactive, and heat-stable compounds. PCBs induce a number of toxic effects, including liver damage, cognitive impairment, and tumor formation. There are 209 cogeners of PCB; about 130 are used commercially, each with varying degrees of toxic effect. Several cogeners produce "dioxin-like effects" and are considered the most toxic PCBs.

With their wide variety of chemical strutures and applications, pesticides raise a number of environmental concerns. Over 95% of herbicides and insectidies reach a destination other than their target. Soil systems, ground and surface water, air currents and non-target species can all be affected by these compounds when they are applied, with the overall effect being the widespread reduction in biodiversity and pollinator populations. Chlorinated hydrocarbon pesticides are especially concerning as their ability to accumulate in the fat of animals contributes to the development of neurological and developmental defects, fetal death, and various forms of cancer. The leaching of pesticides makes the agriculture industry the number-one polluter in the U.S.[55]

Approximately 10–15% of synthetic dyes are released in industrial wastewaters around the world.[56] Their presence in aquatic systems blocks the penetration of light into waters, limiting the growth of phytoplankton along with the larger organisms that depend on these species for food. Dyes and their byproducts may also be directly carcinogenic and mutagenic to living organisms.

One of the most widely used explosives of all time, the nitroaromatic TNT, has been intensely studied in bioremediation strategies due to its abundance and persistence in the environment.[57] It readily binds to soil structures and is not easily degraded by fungi or other microorganisms. BPA and nonylphenol are both endocrine disruptors that mimic the hormone estradiol, causing hormonal imbalances in humans and other animals. These imbalances can result in significant developmental impacts on fetuses and infants and physical and neurological difficulties later in life.

The Shaggy Mane mushroom is known to frequently break through asphalt and create large potholes in the road. Shaggy Manes produce a large amount of spores, making them ideal candidates for mass spore inoculations.

Noted Fungi for CCA

Higher Tolerance

Antrodia radiculosa
Gloeophyllum trabeum
Irpex lacteus
Merulina alcalina
Neolentinus lepideus
Ouedemansiella radicata
Phanerochaete chrysosporium
Postia placenta
Serpula lacrymans
Trametes versicolor

Lower tolerance

Laccaria bicolor
Laccaria laccata
Suillus granulatus

Non-Aromatic Compounds

The following compounds do not contain aromatic rings, yet still present a challenge to microbial and plant-based forms of remediation due to their toxic effects, chemical complexity, and/or overall persistance in the environment.

Chromated Copper Arsenate (CCA)

CCA is a highly antimicrobial compound commonly used to protect and preserve wood. It is largely comprised of the heavy metals chromium, copper, and arsenic. These metals (and especially the arsenic fraction) can leach from CCA-treated wood over time, causing numerous impacts in the environment. When CCA-containing pressure-treated wood is burned, these elements are released into the air where they are breathed by animals and travel on air currents to eventually settle on the surface of soil systems downwind. Degradation of CCA-treated wood by copper-tolerant fungi presents an alternative disposal strategy. The copper oxalate produced by these fungi (moolooite) is insoluble and non-toxic.

Dimethyl Methylphosphonate (DMMP)

This compound is commonly used in the production of various chemical products such as flame-retardants, plasticizers, and anti-foaming agents. It has also been used historically in the manufacturing of several chemical weapons, including the nerve agents VX, Soman, and Sarin. As phosphorous-containing compounds, these chemicals may be best degraded by phosphorous scavenging fungi such as *Psilocybe* species, which require phosphorus for the production of psilocybin.

Industrial Wastewater

The wastewater produced by various industries can cause a variety of problems in the environment. Governmental regulation in some countries requires on site treatment of these wastewaters. In other instances, they may be released directly into local water systems. Depending on the source, valuable products can be obtained through the remediation of these wastewaters, adding an economic incentive to their remediation.

- **Dairy:** The dairy industry is one of the world's largest sources of food-processing wastewater in the world, producing large quantities of whey and lactose that, if released into the environment, can severly impact microbial populations. At least 98 species of yeast are known to utilize lactose. *Candida kefir, Kluyveromyces fragilis, K. marxianus,* and *K. lactis* are commonly utilized to treat this wastewater, with the latter able to hydrolize 99.5% of lactose in 30 hours.[58] Ethanol can be produced in the remediation of whey.
- **Slaughterhouses and tanneries:** Both of these industries release water that is high in fats and proteins. *Candida tropicalis* S001 is one species that has been successfully used to remediate this waste stream. The water's pH must be lowered, then the water is sterilized, inoculated, and fermented to create yeast biomass feed with soluble proteins that can be further processed into methane. The pH can be so low that it is almost sterilizing in itself.[59]
- **Silage:** Silage is a form of animal feed produced by the fermentation of plant matter. In the process of fermentation, a significant amount of wastewater is leached from these plants into fields and ground and surface water systems. The National Rivers Authority considers silage water 300 times more polluting than raw domestic sewage. *Candida utilis* is one species recommended for silage treatment.
- **Breweries, distilleries, and fruit processors:** These industries produce copious amounts of wastewaters that negatively impact aquatic and microbial life. Depending on the fungal species and wastewater being treated, different products result. When *Saccharomyces cerevisiae* is grown on sugarcane molasses, glycerol is produced. *Aspergillus niger* produces citric acid when grown on untreated beet

molasses. And Shiitake produces MnP and laccase during the remediation of malt containing products. Turkey Tail and Pearl Oyster have also been shown to cause a significant amount of color removal from brewery wastewater.[60]

- **Olive mills:** The wastewater created in the production of olive oil and other olive products is toxic and complex, hosting a number of phenolic and non-phenolic compounds. As such, white rot species such as Pearl Oyster, Phoenix Oyster, King Oyster, and Shiitake have been shown to be more effective than yeasts or molds in treating this wastewater.[61]
- **Oil sands:** Naphthenic acids are some of the most persistant and common constituents of wastewaters produced during tar sands mining operations. Their chemical structure implies that these compounds would likely be degraded by the oxidative reactions of fungi.

Strategies for Chemical Remediation

The remediation of chemically contaminated soil and water systems presents the grassroots remediator with a unique set of challenges not encountered so far. Whereas the remediation of metals and microbes passively relies (for the most part) on the independent actions of fungi, efforts targeting chemicals must track the substrate's nutritional profile, pH, temperature, and oxygen levels to ensure that conditions are constantly optimal. These variables have all been shown to play a significant role in determining the efficacy of a remediation protocol and their influence should be factored into any design. To address these challenges most efficiently, the TIMEBITE framework is offered as a means to streamlining the design process:

1. **Test:** If the contaminant is not known with certainty, it should be identified using an analytical method. Testing not only aids in identification, it also helps determine the concentration of the pollutant. Initial concentration levels help determine how efficiently an installation remediated a given compound. Many chemical wastes also contain heavy metals that should be tested for as needed. The naturally present macro and micro biota, soil pH, CEC, and nutrient and mineral content should also be described to further refine a design's strategy.
2. **Isolate:** Following proper safety precautions, the contaminant(s) should be isolated from the surrounding environment as soon as possible. This should be done even if a remediation stategy is not yet determined. Containment methods vary by site. This stage also calls for the collection and isolation of local fungi and microbes for screening trials.
3. **Match:** Research and identify the fungal and/or bacterial species that are known to address the contaminant(s) as well as handle the climate and substrate form (e.g. soil and liquid). Were any of these species found on site?
4. **Evaluate:** Once a number of species have been identified as potential bioremediation candidates, their remediative abilities can be screened and compared for their relative tolerance to the pollutant. Proof-of-concept trials should be conducted to compare the efficacy of each species/strain prior to mass application.
5. **Bulk:** Once a species/strain or assembly of organisms has been identified as an ideal candidate, it can then be bulked up in either solid or liquid media. The contaminant should be consistenly incorporated into the media to ensure continual production of the necessary enzymes. H_2O_2-producing mediators or other additives may also be experimentally included, if possible.
6. **Inoculate:** Once the remediative fungus has been bulked, the chemical contaminant can then be mass inoculated. Co-substrates such as straw will likely be beneficial additions at this time. Bacterial and plant co-remediators may also be included.
7. **Track:** As the experiment proceeds, samples should be periodically tested to track the design's efficacy. If contaminant levels initially decline rapidly but then stabi-

lize, additional nutrients or other additives may be experimentally introduced in an attempt to increase the production of digestive enzymes. Temperature and pH levels should be monitored and managed as well.

8. **Equate:** After the remediation effort has ended, a final assessment should be gathered. Final samples should be taken and tested. If concentration levels are not within safe limits, further treatment may be required. Once an optimal protocol has been developed, it can then be scaled up to address the entire site.

The acronym for the above protocol is appropriate. All of these stages can take a considerable amount of time, depending on the experimental design and depth. Months can pass before results are measureable, especially if species/strains are pre-screened and their mycelium amplified. However, once a site- or contaminant-specific protocol is refined, its application, success, and replication can thereafter be acheived quite rapidly.

Commerical Remediation

Industrial remediation practices are a far cry from the more ecologically balanced systems presented in this chapter. When spills occur on land, a common practice is to simply dig up and incinerate the soil, releasing toxins into the air. Soils may also be extracted and disposed of in a landfill or "washed" with various chemical treatments before being returned to the ground. Or they may be "flushed" *in situ* with a chemical surfactant or co-solvent to move a given contaminant through the ground and into a well, where the resulting wash is pumped out and treated.

Screening and Acclimating

Once candidate species have been identified through research or direct harvest from the contamination site, the next step is to screen these species/strains for their relative remediative capacity. There are several ways to go about this.

Side-by-Side Trials

Once pure cultures of the candidate strains are isolated on agar, tissue samples can be transferred to new plates containing the contaminant. In this new environment the various species/strains can be monitored and their response to the contaminant subjectively compared. If one strain consumes the contaminant much more rapidly than the others, this will be a good candidate for further testing. Introducing the contaminant to a contaminant-containing plate can take two forms:

- **Soaked paper:** Dilute the pollutant through a series of titrations as described for bioassays in the section *Determining Efficacy*. To filter any fungal spores or microbes out of the pollutant, draw up the dilutions in a fresh syringe and then attach a 0.2 μm filter to the syringe. Squirt the liquid through the filter and into a sterile container. Wrap small pieces of paper in aluminum foil and sterilize them for 10 minutes at 15 psi. Once cooled, soak the paper pieces in one of the titrations under aseptic conditions. Place one piece of paper into a petri dish containing nutrified agar and inoculated with a tissue transfer of one of the strains. Using agar formulas with different nutrient concentrations (e.g. full strength, half strength, etc.) may produce different results. For example, low nitrogen levels have been shown to encourage greater remediative effects in some species as the fungus seeks nutrition from the contaminant. This process is helpful for determining how a species responds to a contaminant under different concentrations and nutrient availability conditions, but it is not necessarily effective at increasing the overall tolerance of the strain to the contaminant.
- **Contaminated agar:** Here, the contaminant is incorporated directy into the agar formula at various concentrations (via titrations) along with varying amounts

*Two differing responses to the pesticide glyphosate. On the left Enoki (*Flammulina velutipes*), and on the right the Pearl Oyster (*Pleurotus ostreatus*). Such responses help determine which species/strain is an optimal candidate for a given compound. In this case, the Pearl Oyster stays true to form and demonstrates its insatiable appetite for nasty pollutants.*

of co-substrates, as discussed in Chapter 8. When numerous formulations are tested side by side, the initial concentration tolerance of the fungus to the contaminant can be determined. I suggest trying several agar formulations that reflect the chemical composition of the contaminant. For example, if the compound is comprised solely of carbon and hydrogen, a nitrogen source should be added to the formula. In many studies glucose is also added to media formulas to enable mediator compounds to easily produce H_2O_2. These titrations should not be pressure cooked in the agar. Rather, they should be run through a syringe filter as described above and added to the agar when it has cooled to around 140°F (60°C) after pressure cooking.

When the fungus is successively transferred to plates with increasing concentrations of the contaminant, the strain's initial concentration tolerance level may increase. Once a maximum tolerance level is determined for a given strain, the final transfer is to a plate with a slightly lower concentration than the maximum, allowing the fungus to relax a bit and thus be even more effective in its digestion of the pollutant. This method of acclimating the fungus is helpful for determining the maximum concentration level that a species can effectively remediate at, as well as provide a sense of the additional nutritional inputs that may be needed when the actual installation is implemented. So, play with your formulas. You might waste some plates and agar along the way, but you will learn a lot in the process.

Strain Development on the Plate

Following the concepts described in the section *Developing Strains for Novel Substrates* in Chapter 8, this approach uses spores to inoculate a petri dish that contains the target compound, as described in *Contaminated Agar*, above. Once candidate strains are established, they can be isolated and compared for their relative remediative capacities.

Alternatively, the various strains on the plate can be comingled into a multi-strain liquid inoculum. Once bulked, this inoculum is then used to inoculate grain spawn and ultimately the contaminated substrate. Of the various tolerant species applied, a minority will flourish and remediate the contaminant. If mushrooms ultimately arise from this substrate, spores are then harvested from the fruit bodies and a second generation of spores applied to develop new strains that have an even greater tolerance for the climate, contaminant, and co-substrates found in the remediation zone. Through this epigenetic gene exression, a parent mushroom thus transmits adaptive traits to its offspring over the course of very short generational gaps. This process can be further repeated through multiple generations to develop strains that are highly tolerant to the needs and constraints of a specific environment.

Strain Development on the Substrate

This low-tech approach directly applies a spore spray (as discussed in Chapter 9) to a contaminated substrate in the hope that remediative strains will develop and flourish. If fruitbodies arise, the remediator can create a second spore spray and repeat the process to develop strains with an increased tolerance for the contaminant. While this technique is quite simple, its likelihood of success is rather low when compared to the more refined approach of incorporating co-substrates and large quantities of acclimated spawn.

Screening, developing, and acclimating strains to a contaminant prior to application in the field is recommended to ensure the greatest success of any remediation effort. However, some projects and groups may not have the time, resources, or experience to go through this relatively long process. Do not let these limitations put an end to your remediation endeavors. Many remediation projects have found success in applying commercial spawn that was not acclimated to a targeted contaminant. Spent spawn also works well due to the wealth of digestive enzymes that it contains.

Soil Remediation Strategies

Treating soils that have been recently contaminated with a chemical pollutant begins with containing the spill zone from the surrounding environment. If possible, swales should be constructed on the downhill slope of the area and filled with substrates known to sorb the contaminant(s). These habitat buffers should be built on contour and lined with plastic to collect as much of the pollutant as possible in the event of rain. The sorbing material should be replaced as needed and moved to an off site location for later inoculation and treatment. If rainfall is significant, temporary tarps may be suspended above the contaminant zone to reduce further leaching and sinking of the pollutant.

The most effective species for *in situ* soil remediation tend to be those that naturally inhabit soils (e.g. later-stage decomposers and mycorrhizal species). Wood loving saprotrophs may not persist for long in the unfamiliar substrate of soil. Remediative mycorrhizal species that are found on site should be considered strong candidates for amplification and inoculation. For soils that will be treated *ex situ* in a constructed pile, saprobes are the better choice. Aerating systems (e.g. mycoreactors) can be included in these installations to increase microbial and fungal respiration.

Once the appropriate species/strains have been identified and screened for their remediative potential, their mycelium can then be amplified following standard spawn production protocols. Ideally, the contaminant would be introduced at each stage of spawn production to ensure that the fungus' oxidative capacity will be at maximum efficiency when the mycelium is ultimately applied in the field. As the oxidation process is initiated by some species when nutrient levels decline, these compounds may be added once a substrate is fully myceliated. Conversely, for some species, sufficient nitrogen levels can increase their oxidizing ability.[62] Adding contaminants later in the process also allows for easy visualization of how the fungus responds to varying concentrations of the pollutant. Try several methods for intentionally contaminating myceliated substrates and assume that some will not succeed.

One approach would be to add a small amount of contaminated soil to a jar of grain spawn several days after the grains have become fully myceliated. Once the fungus adjusts to the dirty soil and myceliates it several days later, the jar's contents can then be used as inoculum for pasteurized sawdust. Once the sawdust is myceliated, the bag may be opened and, without breaking the mycelium, top-dressed with more of the contaminated soil. Once the mycelium runs through this layer of dirty soil, the bag's contents can be broken up and applied at a 20–30% inoculation rate into piles of contaminated soil mixed with a non-woody co-substrate, such as straw. The mycelium can be applied in layers or incorporated evenly throughout the substrate. Once the pile is built, cover it with 65% green shade cloth to limit evaporation and retain warmth in the pile. The optimal ratio of contaminated soil to co-substrate will vary by the concentration of the contaminant and the nutritional profile of the soil. Proof-of-concept trials will help determine the appropriate ratio. Inorganic nitrogen sources, such as ammonium tartrate, ammonium chloride, and ammonium sulfate have all been used as co-substrates in remediation experiments.[63]

Rather than attempt to maintain large quantities of fresh spawn in the event of a possible spill, it is much more efficient to contain and collect as much of the contaminant as possible, develop and/or screen strains that are compound-specific, and then bulk up spawn of those strains.

Laccase, LiP, MnP, and H_2O_2-producing mediators have been shown to perform most efficiently in environments with a pH of around 3. But, as these acidic conditions tend to inhibit the growth of mycelium, soils and other substrates should have their pH adjusted to a slightly more tolerable range (around 4–5.5 pH) to balance these conflicting influences on an installation's outcome.[64] For some species, high temperatures have also been shown to increase the rate of degradation. Inoculated soils can be loosely covered in black plastic sheeting to help retain heat. Temperatures should be regularly monitored in such designs to avoid overheating the mycelium. Other influencial parameters include the moisture content and oxygen levels in the substrate.

Water Remediation Strategies

The treatment of chemically contaminated water systems presents the greatest challenge to grassroots remediators. Soluble chemicals cannot be filtered out of water like the insoluble solids of silt and microbes. There is no simple, passive method for efficiently capturing and remediating toxic chemicals that are dissolved in water. The only way that remediators can encourage fungi to significantly reduce dissolved pollutants is through the creation of long-term interactions between the contaminant and the fungi's extracellular oxidation mechanisms. This is very difficult, if not impossible, in large bodies of water. Contaminated water is most effectively remediated when it is collected and treated in containers. In most studies, this constraint has been addressed in one of three ways:

- **Bioreactors:** Similar to the liquid-based cultivation practices described in Chapter 8, remediative mycelium can be grown in jars or tanks filled with chemically contaminated water. As the mycelium grows through the liquid, its extracellular enzymes degrade the pollutant(s), leaving less- or non-toxic byproducts behind. As with other remediation techniques, co-substrates such as glucose or a nitrogen source may be added to facilitate the process. The containers used can take a variety of forms; all are referred to as *bioreactors*. A mason jar with an airport lid and stir bar is a simple, yet effective version of a small bioreactor.

  Contaminated water can be treated with bioreactors in discrete, one-off batches or as a continuous stream. For *batch-fed fermentation* systems, polluted water is diluted and/or mixed with co-substrates in a sealed vessel, sterilized, and then inoculated with one or several species. Filtered air is introduced to the system as the mycelium grows through the liquid until, after a set amount of time, the vessel is opened and the liquid is sampled to determine how effectively the mycelium has degraded the pollutant(s). Many studies on using such an approach were done in small (0.8–1.5 L) tabletop models, a practice that is easily replicable for the community-scale remediator and researcher.

  More elaborate bioreactor systems have been designed that allow for remediated water to leave the fermentation container as more contaminated water is introduced. This is known as *continuous fermentation*. Continuous systems are less practical for community-scale approaches as they require some elaborate equipment and tricky engineering to maintain sterility.

  Both batch-fed and continuous systems have also been used to successfully treat heavy metal contaminated water. When the appropriate fungus is grown in nutrified, metal-contaminated water, the metal ions can sorb the mycelial tissue. The mycelium can then be later removed and properly treated and the water tested for its metal concentration.[65]

- **LC broth:** When remediative fungi are grown in a liquid broth, their oxidative enzymes are released directly into the growing medium. When the mycelium is filtered out of this enzyme-rich broth, the liquid fraction can then be directly applied to the contaminated water to potentially oxidize and degrade a given pollutant. This may sound too simple to be true, but several studies have applied just this approach with great success.[66]

Hair is well known for its ability to sorb PAHs and petroleum hydrocarbons. It is never too early to begin collecting hair from barbershops and making booms in preparation for future spills.

- **Enzyme extracts:** Through a series of chemical reactions, the water-soluble digestive enzymes of white rot species can be extracted from liquid culture broths or myceliated substrates and applied directly to contaminants in a concentrated form. This practice can be quite effective at degrading various aromatic and non-aromatic compounds. One simple, yet effective process for extracting enzymes from fresh or spent spawn is to soak these materials in water for four hours, thereby dissolving the enzymes (notably laccases) into the water. The solids are then filtered out and ammonium sulfate ($[NH_4]_2SO_4$) is added to the liquid to help pull the enzymes out of the solution.

  When the ammonium sulfate dissolves, it forms sulfate anions and ammonium cations. These ions bind to laccase, lowering the enzyme's solubility and causing it precipitate out of the water. The ammonium sulfate needs to be added to the liquid at the proper ratio to create a 70% solution to target the laccase. This should be done in an ice bath to minimize degradation of the enzymes. After being mixed, the solution is centrifuged to condense the proteins. The resulting pellet is then resuspended in a 100 mM (8.2 grams per liter of water) sodium acetate buffer (pH 5) made from vinegar and baking soda. To remove the ammonium sulfate from the laccase, the resuspended pellet needs to be run through a stirring chemical dialysis system at 39°F (4°C) overnight. The dialyzed solution can then be stored at 4°C until use.

  The two drawbacks of this approach are that isolated enzymes are subject to instability, even when placed in a buffer, and the separation of enzymes limits the effectiveness of the fungus' "suite" of enzymes, as noted earlier. Still, I see this technique offering a strong potential for remediating contaminated water systems due to its ease of practice and the commonality of the ingredients involved.

Large-scale water treatment systems that can address hundreds or thousands of gallons of contaminated water at a time are possible if the above principles are properly scaled up. This is a common practice for treating industrial wastewaters. For all of these practices, the highest degree of enzyme production/chemical degradation is obtained when targeted incubation times, temperatures, and pH, nutrient, and oxygen levels are provided. All of these factors vary by species, strain, and compound.

The application of the digestive enzymes produced in the liquid medium of certain fungi, as described above, has been proposed as a viable method for treating plastics.[69]

Fungi and the Plastics Problem

Since the invention of plastics over 100 years ago, countless scientists have tested the vulnerability of these materials to microbial and fungal degradation. Numerous studies have shown that, when buried for a year or two, most types of plastic will be partially degraded by soil-dwelling fungi, especially species in the genera *Penicillium*, *Mucor*, and *Aspergillus*. Some studies have simply placed plastics directly into myceliated petri dishes or bioreactors, with some rather striking conclusions. Turkey Tail has been shown to degrade Nylon 6[67] and *Phanerochaete chrysosporium* can digest bakelight, an early form of plastic made from phenol and formaldehyde.[68] A surprising study from 2012 found that the endophytic fungus *Pestalotiopsis microspora* was able to degrade a liquid form of polyester polyurethane under a variety of conditions, most notably in the absence of air and without an additional carbon source. This discovery alone has raised many questions about the unexplored potential for endophytic fungi to aid in the remediation of not only plastics buried deep inside of landfills, but of chemical pollutants in general. For all this remarkable research, it is surprising to find that very little of this knowledge has translated past the lab bench into viable solutions for addressing the growing piles of plastics that fill the landfills and seas of the world. In the end, it may fall on grassroots remediators to develop sound approaches to solving the plastics problem, perhaps by starting in our own homes.

Remediating Bodies of Water

For the grassroots remediator, the above strategies are effective for addressing the relatively small volumes of contaminated water produced by homes or small businesses. For lakes or rivers, the general challenges of treating water increase dramatically as the variable pH and low temperature and oxygen levels of these large systems significantly influence the effectiveness of a remediation strategy.

For large bodies of water that have been contaminated, control of these environmental variables is essentially not possible. Oxygen is a major concern as the low amount of available oxygen in static water systems limits the ability of fungi to grow and for oxidative processes of chemical degradation to occur. Of the dissolved oxygen that is available in water bodies, the majority is found in only the top few inches, significantly limiting the efficacy of remediation techniques at any appreciable depth. The low temperature of most water bodies also limits the rate that enzymatic reactions can occur, reducing any installations efficacy. As such, attempts to apply white rot fungi directly into such a foreign, harsh environment as a polluted lake will likely result in failure.

Rather than trying to remediate the water *in situ*, the most effective approach would be to contain, collect, and remove as much of the contaminant as possible and treat it *ex situ*. Many insoluble compounds (such as petroleum hydrocarbons) tend to float on the surface of water. Absorbent substrates such as hair, straw, and sawdust can be mixed and stuffed into a nylon mesh or burlap sock and skimmed across the water surface to sorb these compounds. Insoluble contaminants often produce a distinct sheen, indicating their presence. However, these sorbing booms can only capture these surfacing compounds. Depending on the contents of the spill, many other contaminants may have dissolved down into the water column or sunk to its floor. For this unfortunate reality, there are no inexpensive options for community-scale efforts to concentrate or collect these sunken toxins.

Flowing systems, such as rivers, offer many of the same challenges encountered with static bodies of water, but are often slightly more manageable, especially if the river is not very wide or deep. As with lakes, the skimming and removal of insoluble compounds should be incorporated into a river remediation strategy when applicable. Simultaneously, a mycosorbtion system can be installed to collect heavy metals as the water flows through the system. If possible, a small waterfall should be constructed upstream from the installation site to provide additional oxygen to the fungus. The water can also be slightly oxygenated through vortices created by egg-shaped objects or biodynamic flow forms placed in the path of the water. Still, chemically contaminated water flowing through an installation will have very little contact time with the fungi and their enzymes. This is significant as the success rates achieved with bioreactor systems are only obtained after many hours, days, or weeks of fermentation.

Experimental Design: A Primer

Once you have determined the targeted pollutant and the candidate species/strains to work with, the next step is to design the strategy for remediation. In addition to the design priciples discussed thus far, proper experimental design is essential for devising a remediation plan that effectively contributes to the growing knowledge base of grassroots mycoremediators. For all the labor that a remediation project takes to be accomplished, this additional step is well worth its effort for the insights it can provide.

1. **Ask a question:** Asking novel questions is one of the most important and direct routes to refining the field of grassroot mycoremediation and increasing its accessiblility. New discoveries are only made in science through a little bit of luck, a fair amount of educated guesswork, and a whole lot of curiosity. Go where others have yet to tread and never stop wondering, "What if?"
2. **Research:** Next, determine whether this question has been asked and/or answered before and, if not, what information is available that supports the assumptions underlying it. Many scientific journals and databases can be searched online to provide this background. Some are free; others require a membership. University

and public libraries often have memberships to most, if not all, of these databases. Ask local librarians for help researching. Peer-reviewed scientific articles summarize their research in their opening abstracts. If you cannot access the entire study, abstracts often provide a wealth of helpful information. Inexpensive internet browser plugins and computer applications, such as Zotero and Mendeley,[70] are great tools for helping track research documents.

3. **Construct a hypothesis:** Analyze the data from the research to develop a succinct and specific hypothesis that is founded on the information gathered. A hypothesis is like an educated guess that attempts to explain or presume the outcome of an event. They are often constructed in the form "If [I do this specific thing], then [this specific thing] will happen."
4. **Perform an experiment:** Determine a method for testing the hypothesis. Limit the number of variables that can influence the outcome of the experiment by controlling as many parameters as possible. Ideally, only one parameter will be modified during the experiment to provide a clear understanding of that factor's influence. To set a baseline against which the experiment can be compared, include a "control" group that is not modified. Also perform replicates to demonstrate that the experiment is repeatable.
5. **Analyze the data:** Once the experiment has run its course, interpret the data collected. Was your hypothesis correct? Find out by comparing the results obtained in the experimental groups to the changes in the control group. Draw conclusions and identify questions to address in future studies.
6. **Communicate your results:** Spread the spores of your labors by sharing the experiment's findings with the world. If the experiment was properly designed and executed, the study may be peer reviewed and published in a scientific journal. Hopefully, the discovery will lead to new questions and cycles of inquiry.

Good science requires good note taking. For any experiment, develop the habit of keeping and maintaining a lab notebook to track every detail. Record everything, even the mistakes. You never know what you might accidentally uncover.

Putting it All Together: Example Scenarios of Common Problems

To summarize the information in the chapter, presented below are several generic remediation protocols for common site- and contaminant-specific scenarios. As skeletal protocols, use your best judgement and a sound understanding of the contents of *Radical Mycology* to adjust these approaches to match the needs and limitations of a given project.

Brownfield

The generic term *brownfield* is used to describe any track of land that cannot be readily developed or inhabited due to the presence of pollutants in the ground. While the type and concentration of pollutants vary widely for any given brownfield due to the history and age of the site, the following protocol will be suitable for most situations.

1. Determine the site history and safely conduct a field survey.
2. Collect and analyze soil samples to map the contaminant's concentration across the area. Determine whether the contaminant levels are within safe limits.
3. Conduct a bioassay to identify and quantify indigenous fungal and plant populations.
4. Begin cultivating mycorrhizal fungi from the site.
5. Support and amplify beneficial soil microbes through the application of remediative compost tea and other biostimulation practices.

6. Alternately, if the soil is contaminated with a chemical pollutant, seems heavily compacted, and/or is rather devoid of life, consider excavating and treating the soil *ex situ* with the appropriate spawn of one or more screened and acclimated species. Add co-substates if needed. Once the contaminant has been remediated, return the soil to the excavation site while simultaneously inoculating the soil with remediative compost tea.
7. Amend the soil and adjust its pH as needed to decrease the solubility of heavy metal contaminants.
8. Once the indigenous mycorrhizal species/strains have been amplified, inoculate plants known to accumulate or remediate the target contaminants with these fungi. At planting, add worms, biochar, and remediative compost tea to the soil to create a healthy biofilm in the rhizosphere and to enhance the overall soil ecology.
9. Monitor the site over time. Harvest mushrooms and plants that arise and properly dispose of them as heavy metal laden wastes.
10. Analyze the data and share your findings with the world.

Water-Based Petrol Spill

The most effective means for treating chemical contaminants spilled into water systems is to extract them as thoroughly as possible for remediation off site. Remediating microbes and plants can be added to this practice, creating a multi-trophic protocol that offers the most robust response to a spill of pollutants.

1. In advance of any spill, assemble and stockpile burlap or nylon booms stuffed with hair, straw, and sawdust.
2. Immediately following a spill, use these booms to form a dense and complete perimeter around the spill zone to sorb and collect the compounds floating on the water's surface. The shores of the water system should also be lined with booms or straw bales to capture any compounds that escape the containment zone.
3. If heavy metals are present in the spill, barriers of substrates myceliated with fungi known to sorb the target metal can be placed in the way to potentially capture some of these contaminants. The mycelium may need to be thermally or chemically pre-treated to sorb the metals. This would be an excellent application for spent spawn.
4. Once the booms are saturated, they should be moved to a dedicated remediation site and inoculated with the spawn of an appropriate species/strain. Co-substrates may be added while moisture levels, temperature, pH, and oxygen levels are properly adjusted.
5. Once the fungi have run their course, test the remaining materials to determine the presence and concentration of any remaining compounds.
6. If appropriate, hot compost the remaining materials to degrade lower-weight pollutants.
7. The resultant compost can then be used to grow hyperaccumulating plants that will collect heavy metals present in the compost. These plants should later be removed from the treatment area and properly disposed of. Test the final product to determine whether it can be safely used as the growing medium for non-food bearing plants.
8. When all is said and done, analyze the data and share your findings with the world.

Where to Grow from Here: Areas for Research and Development

With 6 million fungal species estimated in the world, it must be asked why mycoremediation research has focused so heavily on a small number of white rot fungi and molds. Though these species have indeed shown potent capacities in their ability to degrade and transform pollutants, their notoriety has, in retrospect, effectively overshadowed the innumerable fungi filling other ecological niches and the unknown capacities that they offer. Apart from *Pestalotiopsis microspora*, endophytic fungi have received little attention for their capacity to degrade plastics or other pollutants. Ericoid mycorrhizal species have been shown to grow in contaminated substrates and under the extreme environment of highly acidic heathlands, yet their remediative potential is essentially unknown. Alpine, thermophilic, litter-decomposing, and soft-rot fungi have all been significantly overlooked, leaving gaping holes in a complete description of what can be considered a remediative fungus.[71] Lichenizing fungi host an incredible tolerance to exteme environments and the ability to demineralize rocks under harsh conditions, yet they too have been hardly examined.

Once the remediative abilities of individual species are more thoroughly understood, an emphasis on combining various organisms into holistic systems that mimic the nutrient cycles of Nature will likely underlie the development of more effective bioremediation designs of the future. Whereas *Phanerochaete chrysosporium* has historically been the archetypal species for many fungal bioremediation systems—despite the fact that its natural niche is unknown—the remediation designs of the future will need to reflect the ecology of the contaminant zone. Successional changes that occur during the complete regeneration of damaged ecosystems must be anticipated. This can be done by integrating ecologically appropriate primary, secondary, and later-stage fungal decomposers over time, along with the remediating microbes, insects, and plants that assist in that recomposition process. This successional remediation concept was even explored in one study from 1978, in which several fungi were applied in succession to positively degrade the plastic poly-epsilon caprolactone.[72]

Improving practices for the development, management, and dissemination of contaminant-specific strains will be critical for increasing not only the understanding of a species' stress tolerances but also the general success rates of remediation experiments and installations that integrate these strains. Increasing the commonality of liquid inoculum based cultivation techniques will undoubtedly be central to developing the most appropriate water and soil remediation strategies. All of these refinements will require a significant amount of time, patience, diligence, and widespread collaboration amongst grassroots mycoremediators to be successful.

To increase the means for effective communication amongst researchers, the development of bioremediation-focused information sharing platforms will be central to translating the lessons derived from aged installations into the collaborative design strategies of remediation practitioners, environmental engineers, and hydrogeologists across the globe. Other fields of logistical support requiring development include the creation of open-source, inexpensive, highly accurate, and easy to use water and soil testing equipment; the networking of low-cost culture banks focusing on the perpetuation of climate-, substrate-, and contaminant-specific strains; and the development of educational tools that enhance and raise awareness around the relevance of grassroots bioremediation as a sound practice. The only area not encouraged for exploration is in the genetic modification of fungi. As has been shown in numerous studies with genetically modified (GM) plants, the long-term effects of releasing artificial DNA sequences into the environment cannot be feasibly anticipated nor measured.[73] Heritage plant varieties are commonly lost due to their unintentional cross breeding with neighboring GM plants, yet these impacts are regarded as necessary evils that outweigh the benefits of cultivating synthetic organisms. I would caution against any similar arguments being wagered for the creation of GM fungi that are promised to increase remediative rates in the lab or environment.

Ultimately, the greatest need for the advancement of these practices is an increase in the number of well-informed grassroots bioremediation educators. This fact is what led to the founding of Radical Mycology and the initiation of the Radical Mycology Convergences years ago. As the insights that come from group collaboration is critical for increasing awareness around the great

potentials that fungi offer, the Radical Mycology Collective has worked to develop the means for anyone interested in these topics to join the Mycelial Network of Radical Mycologists around the world. For, indeed, mycoremediation is one study that cannot be undertaken alone.

Part V

INTEGRATION

Chapter Eleven

The Mycelium is the Message

The physical is inherently entropic, giving off energy in ever more disorderly ways. The metaphysical is antientropic, methodically marshalling energy. Life is antientropic. It is spontaneously inquisitive. It sorts out and endeavors to understand. —Richard Buckminster Fuller

The world will not evolve past its current state of crisis by using the same thinking that created the situation. —Albert Einstein

In our world, complexity flourishes, and those looking to science for a general understanding of nature's habits will be better served by the laws of chaos. —James Gleick[1]

Whenever communities form, communication is necessary and collaboration inevitable. Mycelial networks, ecosystems, and human societies all exhibit this rule of Nature through their shared dependence on participation and symbiosis. When built on many close connections, such systems remain resilient, with each node in the network acting as a leverage point against external pressures. However, if a system is or becomes divided, its cohesion will invariably falter, increasing the risk of invasion and dissolution.

Thus, to remain resilient, a community must ensure that its connections not only remain strong and numerous, but that they are also able to effectively respond to external and internal change. The degree of this mutability directly determines how complex a given community will become, as well as how long it will survive. A poorly connected system with few resources and little room for novelty will not be able to adapt to unforeseen influences. Unable to easily create alternatives, such a system may become overwhelmed or damaged by such changes, especially those that are malignant. Conversely, a highly connected and diverse network allows for the spontaneous creation of new ideas, relationships, and adaptions to form in response to even the most complex of challenges.

Such emergent behavior takes countless forms. It is seen whenever a fungus acclimates to a new toxin, when mycologists collaborate to uncover a novel theory, when a neighborhood bands together to build a food forest, or when a social movement effectively rises against oppression. If greater connectivity is needed, a common mycorrhizal network may expand from one plant to hundreds, while a cooperative company would bring on new members with unknown capacities. And if the environment demands change, a plant's community of endophytic fungi could turn saprotrophic, just as an objectionable billboard demands détournement by culture jammers and social critics.

These forms of novelty ripple out across an immediate community, eventually influencing other networks nearby and other systems that develop over time. In the mycelium of history, no event is isolated from the rest of the universe. The evolution of fungi in the distant past is as equally tied to a slice of tempeh as the farmer and mycorrhizae that grew its grains across the continent. One's daily habits nest within the whole of one's life, just as that life is connected to the physical networks of an ecosystem and planet as well as to ancestors and coming generations. This is the "spore effect"

that *systems theory* presents. In this model, a seemingly insignificant cell is recognized for its ability to travel the world, lie in wait for centuries, and still initiate vast changes in a forest's evolution. On even the longest time scale, the primary cause behind any effect remains a mystery, so entwined is worldly experience.

Implied in this elusive connectivity is a concept underlying the field of *chaos theory*: because each act carries an unknown and immeasurable potential, objects and their interactions are essentially impossible to thoroughly describe. The result is that our descriptions of the world must be recognized as mental constructs, primarily created to make sense of the universe's unintelligible and infinite chaos.

Such a conclusion is potent. On one hand, it calls into question every individual's relationship with objects, people, and concepts, as well as the existential assumptions that underlie them. While on the other, an acceptance of chaos provides any observer with the freedom to more appropriately reorganize concepts and their relationships into novel arrangements, especially when such reshuffling can be reasonably argued. While such mutability in perception has the potential to create incoherent interpretations of the world (a danger that must be avoided in the search for truth), it also allows alternative worldviews to have an equal claim to be "right" when compared to perspectives that are more commonly accepted. The creative ability to see things in new a light is what leads to the creation of poetry, scientific breakthroughs, subcultures, and anastomoses between hyphal branches. Updating descriptions of the world may even be necessary if a culture desires to adapt to changes and evolve. If outdated models prove defective or contrary to observations of Nature, emergent paradigms that are more successful must be allowed to flourish if survival is to be ensured.

As highly connected and distributed webs, the unpredictable fungi provide a clear model of the above concepts. Not only are mycelial networks emergent expressions in and of themselves, they are also intimately linked to the emergent behavior in their ecosystems. Humans seeking social systems that model such effective patterns directly benefit from a study of these qualities distributed throughout the Chaos fungorum. Through a mycelial lens, life's various facets can be seen holistically, enabling one to create models that account for variables across numerous systems in a manner that is methodical, yet natural.

The Olympia Free Store in Olympia, Washington: a volunteer run exchange site and node in the local commons.

This is a powerful tool, capable of assisting in efforts for social change by enhancing one's ability to understand, integrate, and intelligently design cultural models that reflect the capacities and desires of all those involved. At the same time, thinking in systems helps address the multi-faceted web of dynamics that enables many social and global problems to arise. While a *radical* (from the Latin *radix*, "root") analysis of any issue gets to the root of the matter, a *radical mycological* framework expands to understand how that root is connected to all others around it.

Wherever (and whenever) in the universe available energy and resources are abundant, self-organization leads to increasing complexity of activity and structure.

—James Gleick[3]

Once the mycelial thought is learned, it is impossible for it to not influence all of one's activities. Connections form easily and yet stay malleable enough to be revised as new information emerges. As the actions of this adaptive thinking process go on to affect the world, they are built upon by others, creating a feedback loop throughout a community. If sustained, these loops have the potential to build other systems, each with their own feedback loops, leading to an exponential increase in complexity and resilience in the meta-system. As these systems stack, integrate, and synchronize, they refine the meta-system's ability to learn from, create, design, evolve, and self-organize itself into the most appropriate emergent model that the meta-system's environment requires. In the theory of *self-organized criticality*, the mechanisms that lead to minor events are the same that lead to major ones. Thus, a forest never reaches a state of equilibrium, but constantly advances from one state to the next. So too can a group of humans that initially organizes around a single issue create a whole culture that is informed, competent, and clear about its values, leading toward focused designs for regeneration in the meta-culture.

To reach this state of self-guidance, it is imperative that communities create and maintain a wide array of open access spaces where connections can easily form. Mycelial networks act as these bridges for a forest, but in urban centers the creation and maintenance of the commons is a challenge that must be intentionally overcome. Beyond the spread of information that internet-based communication provides, the physical and non-mediated interactions that occur in plazas, community gardens, parks, and neighborhood street intersections form the web of experience that holds a community together. It is in these instances that people free themselves from industrial, technological, and state pressures to find new allies, address grievances, learn skills, redefine models, or throw block parties, the emergent act of collective joy. But without these spaces, a community loses both the ability to easily connect and the resiliency that those connections bring. To protect the commons is to protect the mycelial networks that build the world around us.

Connected communities can easily distribute tools and resources. Knowledge can be shared between elders and the young with ease, while information from the individuals and hyphal branches on society's periphery can be heard, influencing the growth of the entire network. As connections knit tighter, these exchanges naturally lead to the design of local economies that support place-based art, education, and social organization. Such "core-periphery social networks" are highly stable and resilient as they allow for an efficient and natural division of labor as well as the means to ensure that support is accessible to all those in need.

As communities build in number, cross-fertilization can begin between them. Where two groups are compatible, alliances may form, turning isolated cultures into wide-ranging hybrids with an emergent vigor. At the same time, other cultures may cohabitate independently, maintaining the diversity of tactics that increases resilience in the meta-system. Such respectful, but distanced relationships are seen wherever mycelial networks share a common substrate yet remain autonomous behind well-defined boundaries. The result is a network of local community and bioregional systems that are rooted in place and not blurred in by imposition of a global "no-place culture."[2]

For humans and hyphae, the freedom to diverge, differentiate, isolate, and express is inherently required for emergence and resilience to be ensured. When growth limits are imposed on a system, a presumption is made of that system's ability to manage chaos and create novelty. Such limitations are not only impossible to maintain, they also work against Nature. It is only when spores self-liberate and spawn new strains that a culture adapts. From these novel centers a new hope for survival is born for not only the singular system but the greatest system it can touch: Earth. Beneath the physical acts of working with fungi, it is this message of connection that lays deepest. At the edge of the every culture new alliances rise and fall as each learns from the creations of the other, endlessly branching, expanding, and adapting, from one hypha to the next.

The definition of insanity is doing the same thing over and over again and expecting different results.

—Albert Einstein

Anyone who tries to make a distinction between education and entertainment doesn't know the first thing about either.
—Marshall McLuhan

Digging to the Rhizomorphic Level

When one looks closely, a given system is not influenced merely by the actions of those involved, but by the knowledge and assumptions that lead to the occurrence of those actions. As a mycelial network crosses the soil, each anastomosis closes a synapse in the mind of Nature. Carrying the desires and threats of a habitat, hyphae grow as vivid expressions of the chance to learn that is offered in each moment. Combined, they are the collective underground consciousness of Earth. And through their acts, that knowledge's potency is expressed, from the assembly of a single fruit body to the liberation of a million spores.

Knowledge is the substrate of life experience that every hypha and human integrates into its being. As information stores increase, they design the mycelial network of life experience, forming new connections as the web becomes increasingly dense. New events recall and connect to those of the past, exposing metaphors between disparate experiences. And when new ideas are encountered, the web's capacity to appreciate novelty increases, offering new means to combat barriers to self-reliance and increasing one's ability to adapt.

The size and structure of a knowledge web influences all of the other webs that it encounters. By sharing ideas and experiences, each web informs the future branching and weaving of the other. This co-creation is threaded throughout the substrate of the world, forming innumerable connections that transform small moments and ripple out, nudging the paths of all who follow toward substrates never before imagined.

As we weave our lives for a limited time, the shape of our personal knowledge web stands as a reflection of all the others we have encountered, as well as of the caliber of the insights gleaned from those moments. All experiences influence our actions, our trials, and the thickening of rhizomorphs along the routines of motivation. As connections break and anastomose elsewhere, each mycelial life weaves its own distinct and tangled map of time on Earth, never to be repeated.

We are constantly at the leading edge of that web, but the quality and direction of our experiences there can only expand with the vigor that they were built from as they are propelled forward by challenges being faced. Likewise, if that growth is hindered or cut off from the resilience brought by novelty, it could wither within constrictions and perish under stagnant repetition.

For many, the information that constructs their mind's web is not derived from a range of direct experiences in the world, but from the experiences and opinions of others. As a whole, human knowledge has become so complex that the thought of studying more than just a few subjects is overwhelming for most, leading the masses to accept the conclusions offered by external "experts." But, though a well-intentioned pedagogue can guide a student to achieving their greatest aspirations, a malignant teacher can quickly impede an individual's growth. Thus, the challenge for any person seeking to build the most resilient knowledge web is to know which teachers and opinions to trust.

Today, innumerable opinions stream from the media and the education and political systems of the world. For all the benefits that the information age has provided, the challenge humans now face is not so much in trying to learn about an issue, but in successfully navigating the innumerable views that surround it. The information age is a blessing for how it has increased access to knowledge and the ability to express imagination, but it has also been a curse for its power to pollute the soils of wisdom with faulty information.

To navigate the information substrates around us, our knowledge webs must hone their ability to quickly observe, assess, and discern the truth in whatever forms it takes. Once embodied, such a skill leaves any thinker able to guard against philosophical attacks and to design a web of analysis that is not entirely sourced from external networks. Once an individual is truly able to think like a fungus, they are no longer held to the opinions of others. This enables one to grow beyond the limits of imposed belief systems and create a life that reflects the best desires for themselves, while still accounting for those in their community.

The lineage of human understanding is often called a "great conversation," one that germinated with our earliest ancestors and has endlessly branched through all generations since. This conversation is the grand network of human thought, inlaid with contexts as rich as each conveyor's life

experience. As this web expands, novel points of unification arise in the endless process of cultural understanding, articulation, and evolution. Through a study of fungi, one can learn how external forces influence this web and how one's actions can spread the most resilient spores of insight to the mental substrates of those that follow. As we learn and our internal knowledge networks grow, we each add to this conversation's connectivity and expanse, generation upon generation, with each small thought and every big idea.

The Broken Web of Knowledge

The average person gains much of their ability to interpret and describe life experiences during a decade or two of public education. During their formative years, most children are placed under state controlled structures that define what the child is to think. As that child turns into an adult, all that they learned in school is carried on to define what is worth studying and, more importantly, how one is to learn about—indeed, *think* about—a given topic. Unfortunately, the learning models presented in public schooling are not only limited, but detrimental. Before one can begin to think like a fungus, they must first identify and dissolve any imposed barriers to their learning and growth processes, such as those imposed by the state.

School is like starting life with a 12-year jail sentence in which bad habits are the only curriculum truly learned.
—John Taylor Gatto

For the bulk of the last few thousand years, education systems in western societies were structured quite differently than the rigid, subject-based model that is now common around the world. As opposed to studying an assemblage of disconnected facts, students of the past were largely encouraged to study on their own and to explore those topics that interested them. Along with this freedom, the student was also given robust skills for logical thinking that enabled them to analyze a topic quickly and ultimately develop their own understanding of it, derived from personal investigation. Such studies often took place in small one-room classrooms ("dame schools") in which students of different ages learned from and taught each other. This not only increased the older students' ability to express ideas and inform others, it also created mentor-peer relationships and mutual respect amongst the differing age groups.

In the 19th century, the dame school model slowly began to be replaced by the enforced schooling system. As detailed in the many great works of author and former public school teacher John Taylor Gatto,[4] this shift began when the Prussian government devised an education system that sought to mold students into non-critical, obedient citizens. Under the Prussian model, curriculum was no longer left open to interpretation by teachers and students, but regulated by the state.

In our dreams, people yield themselves with perfect docility to our molding hands. The present education conventions of intellectual and character education fade from their minds and unhampered by tradition we work our own good will upon a grateful and responsive folk. We shall not try to make these people or any of their children into men of learning or philosophers, or men of science. We have not to raise up from them authors, educators, poets or men of letters, great artists, painters, musicians, nor lawyers, doctors, statesmen, politicians, creatures of whom we have ample supply. The task is simple. We will organize children and teach them in a perfect way the things their fathers and mothers are doing in an imperfect way.
—John D. Rockefeller's General Education Board

In the high class of Prussian society, only 0.5–1% of students were given the actual skills to think strategically and contextually. These lucky few went on to become future policy makers and rulers of the country. Below them, the next 5–7.5% of students were taught to take on the management of society and grew to become the engineers, architects, doctors, lawyers, and general problem solvers of the country. The rest of the population attended "people's schools" where one's proficiency was measured largely by their ability to obey the teacher's commands and to memorize random data, regardless of its merit. By dividing class lines along degrees of intellectualism, the Prussian government was able, in just a generation or two, to slowly shift the mass culture's relationship with authority from a critical to subservient form.[5]

This system was so successful that despite frequent—and at times violent—resistance, it was soon imported to the United States where it was further refined, largely due to the private funding of major industrialists of the early 20th century, such as John D. Rockefeller and Andrew Carnegie. Since that time, the compulsory education system has only been further embellished in the United States and around the world.

In Gatto's summation, nearly every aspect of the enforced public schooling system is designed to support the state. School teaches, directly or indirectly, to place the planning of one's life into the hands of other people. In the classroom, the teacher is commander and chief, dictating what is learned, how time is spent, and what value will be attached to the work that students produce. In a world filled with an infinite number of things to learn, curiosity is partitioned into a small set of inane assignments where thinking or spawning outside the box is not encouraged. The teacher's authority is unquestionable, a submission to hierarchy that the child learns to accept in school

Education should aim at destroying the free will, so that, after the pupils have left school, they shall be incapable, throughout the rest of their lives, of thinking or acting otherwise than as their schoolmasters would have wished.
—Bertrand Russell, The Intended Result of Education

and throughout the rest of their life. This stifling of creativity and self-expression leaves the child endlessly searching for external guidance and validation, whether from authority figures or celebrities, rather than from their own sense of self-worth. As Gatto puts it, if a child is never given true responsibility, s/he will remain child-like beyond necessity—s/he may grow old, but s/he will never grow up.

The child is also deprived of the ability to think efficiently or to even plan their life to achieve goals. Public schools do not teach children to think in context or to connect concepts from different areas of life. Rather, schooling's emphasis on memorizing disconnected facts in discrete "subjects" leaves the child with an incoherent view of history and cultural development. Removed from Nature and the patterns of fungi, the child is deprived of sustained contact with pattern- and systems-based thinking models. Unable to think abstractly, objectively, or with historical contexts, the child is also unable to grasp how the world arrived at its present state or how the actions of a single individual can shape the present and future. This is further exacerbated by the ringing of the Pavlovian bell that tells the student to abandon their work as if it doesn't matter, for it is only the grade marks of the overbearing teacher that can place a value on the work of the child. Over time, the child can no longer view learning as its own reward or appreciate knowledge for its ability to enrich one's life. In the end, the child is left unable to think for themselves, to value their own work, to have relationships that are not based on requirements or outcomes, to investigate taboo topics, or to challenge ideas that they are told to accept.

The Trivium Method: A Mycelial Means of Digesting Information

Where all think alike, no one thinks very much.
—Walter Lippmann

To unschool one's self from the enforced education model is the first route away from its negative impacts. Unschooling models come in a variety of forms. Homeschooling, Waldorf education models, and the Free Skool movement[6] all encourage self-education alongside the spread of information that is outside and beyond the limited curricula of mainstream schools. Thankfully, as Gatto points out, it is never too late to improve the way you think.

If we gained a non-material philosophy that found meaning where it is genuinely located—in families, friends, the passage of seasons, in nature, in simple ceremonies and rituals, in curiosity, generosity, compassion, and service to others, in a decent independence and privacy—then we would be truly self-sufficient.
—John Taylor Gatto

By developing the means to set aside one's beliefs in the search for honest answers, one can begin to explore the richness of the world's information webs unhindered and, in time, find the substrate that is most vital to their survival. This willingness to think objectively, regardless of the outcome, is primary to the development of the most vigorous webs of knowledge. Before one can spread personal spores of inspiration, they must first develop original ideas to contain within them.

Luckily, one does not need to start this process empty-handed. Great minds of the past discovered the best means to think rationally and clearly. Not too surprisingly, perhaps, one of the best of these models reflects the growth of mycelium and the fruiting of mushrooms. By mimicking the mycological thought, one can learn to effectively assess, filter, defend, and express the most empowering and nourishing substrates of knowledge the world has to offer.

This model, known as the Trivium Method, framed the education methodology for dame schools as well as the Greek philosophers who developed it. Just as hyphae discover, digest, and transform substrates into fruiting bodies, the Trivium enables students to gather, process, and express information in a rigorous and systematic manner. Indeed, if knowledge is mycelial, its acquisition must take a similar form. In short, the Trivium Method is performed in the following three sequential stages.

Grammar / Assessment / Knowledge

Unlike the specific grammar of a language's rules of operation, the general Grammar referred to in the Trivium method refers to the raw data of facts, terms, and concepts that define the limits of a subject. In this stage, one answers the questions *Who, What, Where,* and *When* about a subject. This is done by taking into account all perspectives and opinions on the topic, regardless of their origin. The data is collected, but not interpreted. Terms are defined to clarify discussions, and general topics of study are identified. Information is organized prior to analysis, creating a fully mindful and objective knowledge base from which conclusions can later be drawn. *This stage reflects the way by which mycelium navigates and assesses its environment's substrates, inhabitants, and external pressures.*

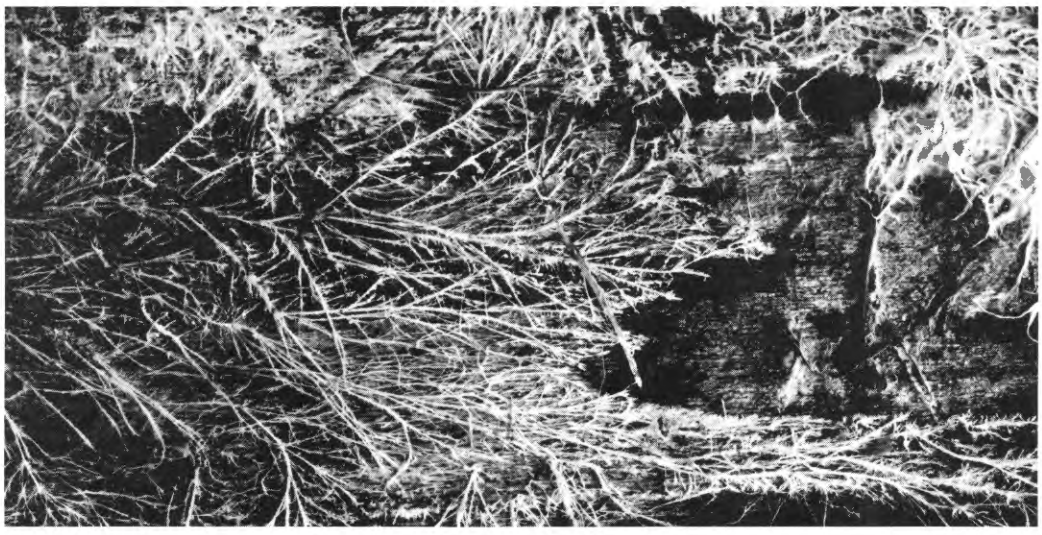
Logic / Digestion / Understanding

Once all the available information on the topic has been gathered, it is then possible to confidently sort and interpret this data to understand *Why* the topic came to be. All contradictory information is investigated to determine which perspective is accurate. Often, an understanding of logical fallacies is applied to filter out poorly constructed arguments, remove contradictory information, and establish which opinions are based on verifiable information. The end result is a conclusion based on rational, non-contradictory information. *This stage is reflected in the digestion of viable substrates by mycelium and in the anastomoses of hyphae to form new and interconnected branches in its web of information. Harmful or non-viable substrates are rejected and antagonists are removed until soundly structured mycelial knowledge (Logic) prevails.*

Logical fallacies are errors in reasoning. Hundreds have been identified. Common fallacies include Ad Hominem *(attacking a person's character instead of determining the quality of their arguments),* Ad Verecundiam *(appealing to an authority figure's opinion regardless of their argument's validity),* Appeal to Popular Belief *(believing something because other people believe it, also known as groupthink), and* Red Herring *(the use of distracting or irrelevant information to derail a conversation).*

Rhetoric / Fruiting / Wisdom

This stage translates the Logic arrived at in the previous stage and expresses it in a coherent form, such as writing, public speaking, or a highly refined fruit body. Rhetoric provides the *How* of a subject. *Here, the knowledge that the mycelium has acquired, filtered, and digested turns from a mass of Logic into a discrete expression of wisdom. Expressing its inner knowing, the mushroom can spread its spores, passing complex ideas into the fertile substrates and minds of the world.*



As society rapidly changes, individuals will have to be able to function comfortably in a world that is always in flux. Knowledge will continue to increase at a dizzying rate. This means that a content-based curriculum, with a set body of information to be imparted to students, is entirely inappropriate as a means of preparing children for their adult roles.

—John Taylor Gatto

The elegance of the Trivium Method can be applied to nearly any facet of human life. In fact, most people frequently apply a similar method for solving discrete aspects of life without realizing it. However, the Trivium Method is most efficiently applied when one consciously integrates it into a daily, mycelial practice.

For many people, it can be hard at first to make the Trivium Method habitual, just as it can take time for a mycelial mass to acclimate to a new substrate or environment. Often, about two years of practice are needed. But, once mastered, this system enables one to navigate any topic, to have the flexibility to entertain any idea without necessarily embracing or rejecting it, and to be freed of social constructs. The Trivium Method is so effective that it is not only reflected in mycelial growth but also in the scientific method (observation, hypothesis, extrapolation, and the development of a repeatable experiment), philosophy (metaphysics, epistemology, ethics, and aesthetics), and even military tactics.

Once the Trivium is well understood, the student can then move on to learning any subject with ease. Gatto suggests reviewing the curricula of the world's most elite private boarding schools, where global leaders learn the skills that not only intellectually empower, but also increase confidence and social capital. In these schools, the arts and sciences are emphasized alongside social etiquette and self-mastery. Like fungi, these schools blend all the resources in their environment to create a lifestyle that is well-rounded and able to navigate any situation with ease. In sum, their curricula tend to emphasize the following processes:

- **Developing a theory of human nature** by studying history, philosophy, theology, law, and the classics of painting, sculpture, music, poetry, architecture, theater, dance, and literature. *The fungi retain a rich ancestral and genetic memory that is expressed in the multitude of niches they occupy.*
- **Learning the inner workings of the major institutional forms** (e.g. courts, corporations, the military, economics, and the education system). *The fungi are found inside of nearly every plant and animal in the world; they influence and understand the workings of their entire ecosystem.*
- **Developing good social manners** to build long-term and successful relationships, alliances, and opportunities. *The fungi anastomose with their kin and form symbioses with numerous allies in their environment.*
- **Learning to access any place and any person in society.** *Fungi are everywhere, constantly searching, learning, and interacting.*
- **Developing personal responsibility** for one's actions and commitments, pride in taking on tasks, and a personal code of standards in private and public life. *The fungi are resilient survivors, able to adapt to any new circumstance. Each species and strain expresses needs and abilities that reflect its environment. They express what they desire and are not commanded by others in their environment.*
- **Working independently** for extended periods of time. *Many fungi work diligently on even the most demanding tasks for days, years, or millennia.*
- **Practicing physically demanding and independent activities** to develop a sense of grace, bodily confidence, and the ability to manage physical emergencies. *Fungi are unstoppable masters of their environment.*
- **Managing challenges of all sorts.** *The fungi constantly challenge themselves to address new substrates and niches, often with the result of greater resilience than before.*
- **Learning methods of accurate observation and recording.** *The fungi reflect the state of their environment in their patterns of growth and fruiting and transmit that knowledge through their spores.*
- **Maintaining a habit of caution in drawing conclusions** and constantly developing, testing, and honing personal predictions. *Fungi may take weeks to acclimate to a new substrate. But, once the best means for digesting that substance is determined, the fungus can grow with relentless vigor.*
- **Mastering self-expression** via writing and public speaking. In other words, *spread your spores.*

Media, Mycelium, and Movements

Apart from education systems, the second main source of information for many people is the conduits of opinion known as television, movies, magazines, and billboards. The tools of the media establishment mold society's perspectives, creating value systems that define desires, limit awareness, and craft artificial needs for products or protection. Just as public schooling teaches students what to think, the media instructs their audience on what to want and what to avoid. The media shapes the information webs of society, just as bulldozers and chainsaws destroy the ancient mycelial networks of the world.

Applying the Trivium Method to the information presented by the media is the first step to dismantling its influences. Just as a mycelial network must defend itself from unhealthy substrates and infections, so must the media critic learn to discern between what it true and what is false in the variety of opinions presented on screens or in print. This analysis begins with recognizing where lies are being perpetuated in the media and spreads out to determine how the media constricts a culture's knowledge web. Just as the fungi relentlessly work to break free of artificial containers, the media critic must look at how the entire media apparatus shapes the world, beyond the topical issues of a singular movie or song.

Art is anything you can get away with.

—Marshall McLuhan

For the most part we do not first see, and then define, we define first and then see. In the great blooming, buzzing confusion of the outer world we pick out what our culture has already defined for us, and we tend to perceive that which we have picked out in the form stereotyped for us by our culture.

—Walter Lippmann

It is often very illuminating... to ask yourself how you got at the facts on which you base your opinion. Who actually saw, heard, felt, counted, named the thing, about which you have an opinion?

—Walter Lippmann

The conscious and intelligent manipulation of the organized habits and opinions of the masses is an important element in democratic society. Those who manipulate this unseen mechanism of society constitute an invisible government which is the true ruling power of our country. We are governed, our minds are molded, our tastes formed, our ideas suggested, largely by men we have never heard of. We are dominated by a relatively small number of persons who understand the mental processes and social patterns of the masses. It is they who pull the wires which control the public.

—Edward Bernays

[People] are rarely aware of the real reasons which motivate their actions.

—Edward Bernays

Limits to Growth

In 1922, political commentator Walter Lippman wrote *Public Opinion*, the first book forecasting how the emerging media systems of the world could and should be used to guide the development of culture. To Lippman, the increasing complexity of industrial life had made the world so complex that the average citizen was unable to make well-informed decisions about domestic or foreign policies and that, in effect, their opinions should be irrelevant to policy makers. Unable to think clearly, Lippman claimed that people constantly created subjective, biased, and abridged mental images of the world, a "pseudo-environment" that could not be trusted. Lippman concluded that the bulk of society was unable to govern itself and that an administrative body was needed to help guide a culture's growth, aided by the influence of the media.

Nearly two decades later, Sigmund Freud's nephew, Edward Bernays, suggested that the psychoanalytical process developed by his uncle could not only be applied to individuals, but to whole societies, and thereby achieve Lippman's suggestions. Up to that point, advertising campaigns for products or political ideas had largely been based on an appeal to rationale, often by highlighting a product's craftsmanship and logically beneficial attributes. Bernays argued that such a model was unreflective of what truly motivates people to buy an object or belief in a candidate. Following Freud's analysis of the human mind, emotions and feelings were deemed more influential to the non-critical mind than logic could ever be. Thus, to profoundly guide a person or society, the media had to intentionally work to influence the emotions of their audience.

Throughout his life, Bernays proved that by using powerful symbolism and charged language, an audience's critical faculty could be easily bypassed as an advertiser sought to sell them a product or belief. Campaigns for dish soap and DEET promised to make life easier and more enjoyable. Political ideologies appealed to needs for protection. And the desire for external validation was used to create beauty standards and cultural divisions. In place of the term "propaganda," which had become tainted during World War II, Bernays named his marketing tactics "public relations."

Today, Bernaysian methodology is ubiquitous in the media produced by the six companies that create 90% of the entertainment in the United States. These companies (GE, Disney, Viacom, News-Crop, Time Warner, and CBS) are the molders of public opinion and the creators and co-opters of the memes that hold those opinions together. By limiting solutions and analyses, these corporations stand as key determinates of a society's political breadth. To control a person or society's information web, the media's success is no longer based on the integrity of its argument, but by how well its artificial representations can be accepted as reality.

Without recognizing and deconstructing these more invisible constrainers of a society's information web, their growth and evolution will forever be hindered. To truly embody the mycelial lens, one must utilize the means to digest and decompose these corporate containers and to spread

You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete.
—R. Buckminster Fuller

beyond their grasp to form more resilient means for communication and cultural change that are based on the patterns and principles of Nature. Otherwise, the depth of any culture will only be defined by the degree to which it allows artificial constructs to influence public opinion, the mycelial network of common language.

Mycomemetics: Be the Media, Spread Your Spores

In contrast to the limited narratives of corporate media, the freedom of expression provided by independent media platforms enables anyone to spread their spores of inspiration into the world. As the printing press, photocopier, and digital video and audio tools have proven, open access to media creation and information dissemination is imperative for the creation of emergent cultures. By sharing ideas and stories that are otherwise ignored by the major media outlets, independent media can spawn community and knowledge networks outside the bounds defined by corporations or the state. Indy media enables people to learn about social movements, acquire life-changing skills, and address environmental destruction practices that are happening in their bioregion. Everyone has novel insights and ideas to offer the world, and independent media is the sterigmata from which those ideas launch. These ideas become memes that benefit the strength and longevity of local values. As they spawn, fruit, sporulate, and evolve, the ideas created by a people can, en masse, lead to the creation of whole new cultures and ways of being built from the mycelial network of a self-directed culture. To live like a fungus, one must spread their spores.

Meme: *Any cultural idea, behavior, symbol, practice, or style that spreads from person to person within a culture by means of mimicking and/or replication. As opposed to the originality of individual ideas and sexual spores, memes are cultural analogues to conidiospores in the way that they self-replicate and respond to selective pressures.*

Mycomimicry: Radical Mycologists as Change Agents

The application of the mycelial lens can be tangibly applied to the design of cultures and communities in a variety of ways. On the last day of the 2011 Radical Mycology Convergence (RMC), a brainstorm session was held with all in attendance to identify means of spreading the skills and insights behind the Radical Mycology movement. Of these suggestions, one of the most accessible was the creation of regional Radical Mycology groups that could serve as local hubs of mycological knowledge.

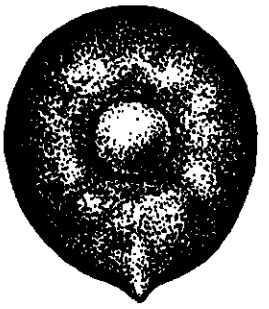
Since that first RMC, several Radical Mycology groups have developed alongside supportive infrastructure and resources provided through the Radical Mycology website. Depending on the interests of a group's members, emphasis may be placed on cultivation, remediation, or raising public literacy around fungi. At their core, all groups follow the principles of the Radical Mycology movement: share mycological skills and build coalitions among diverse organizations in a solution-oriented manner.

The rest of this chapter contains some of the most effective group facilitation skills for organizing a Radical Mycology group or project. However, these skills also extend to other facets of life, from interpersonal dynamics to designing whole societies. Like learning any new skill, facilitating groups, meetings, and events can take a fair amount of time and persistence. But, like the fungi, Radical Mycologists are in it for the long haul. So if you are new to the following concepts, take some time to read the following section and review the additional information provided in Appendix M on group and meeting facilitation.

The Spore

The first step in forming a Radical Mycology group is to determine where and how it would be most supportive of the community at large as well as most supported in return. Take stock of the group's existing community connections, materials, and skills. These will help determine which goals can be accomplished immediately and what holes need to be filled to achieve long-term goals. Next, get the spore rolling by setting a date and location for an initial meeting. Give yourself at least two weeks and spread the word by putting up flyers, sending press releases, informing your local mycological society, and listing the meeting on local (online) event calendars. Two days before the meeting, send out reminders to people whom you know are interested.

The first meeting is where the mycelium meets the substrate. It is where the first brainstorm sessions occur to get as many big and small ideas out. The meeting facilitator should ensure that everyone understands the topics and skills being discussed. It is strongly recommended that all members leave with some sort of task to accomplish before the next meeting. This will ensure that all members are invested in the success of the group.



As the group evolves, this inclusion should also expand to making sure that each member is able to take on any task that they wish and that information and resources in the group are openly shared. Groups that are filled with equally trained and supported members have the capacity for maximum longevity. This is akin to the sharing of nuclei throughout a mycelial network. When all members are able to rotate and evenly distribute tasks, the potential for "burn out" is reduced. By increasing the numbers of effective connections between different branches in the group, groups as a whole can develop a more decentralized network of knowledge, experience, and influence, thereby strengthening the network and its community on the whole. Each member offers their own spores to the group. Through the collaboration of two compatible ideas, whole new strains of thought give rise in the evolution of Radical Mycology.

Spawning Networks With Effective Signaling

Just as mycelial networks rely on clear communication to assess their environment, so do humans interact most effectively when their communication methods are direct and reciprocal. This can sometimes be challenging in a Radical Mycology group where the topic of mycology brings together a diversity of people with varying communication styles. Whether inside or outside of a meeting, such communication barriers can lead to misunderstandings. An effort must therefore be made to consciously avoid these barriers to the creation of effective communication systems and, ultimately, mutually beneficial, symbiotic relationships.

Words extend like hyphae into the mental and audible space between individuals to unite a people in through a common network of shared expressions. When these extensions of intent are expressed effectively, reception is positive and connections are formed. If an approach is antagonistic, parasitic, or pathogenic, defense mechanisms develop in the receiver, and the chance for symbiotic collaboration disappears. As one refines their means for developing mutualistic relationships through communication, they enhance their ability to build stronger mycelial networks among a diversity of individuals.

Luckily, the methods for good communication are simple. The first step to avoiding conflict is to address concerns as they arise and not wait for them to become a major issue. At the same time, the listener must work to respectfully and actively listen to the requests of the other person, and attempt to find a balanced dynamic between the two. This is akin to a mycelial network defending itself from others in its environment by setting clear boundaries that are, ideally, respecful of the boundaries of the others involved in the exchange.

If an issue is too challenging to discuss directly, it is best to structure one's desires in objective/subjective terms that express one's internal response to another's actions without inherently judging the character or intentions of the other person. This is similar to the communication between partners in a mycorrhizal relationship where both partners must communicate their needs and experiences to find agreement on how to coexist. However, mycorrhizal relationships sometimes prove untenable and must break apart, just as not all people are compatible.

Decision Making and Hyphal Branching

Along with creating good standards for communication, Radical Mycology groups should also consider how decisions are made. Depending on their needs, groups tend to choose from one of the formats listed to the side. The consensus model is especially notable due to its similarity to some aspects of mycelial growth.

The consensus model requires all involved to agree on a given proposal before it can be enacted. As opposed to electoral democracy, this model is a form of direct democracy in which every voter has an equally respected opinion. When consensus models are enacted effectively, they can

Decision Making Models

- *Unanimous agreement.*
- *Unanimity minus one vote.*
- *Unanimity minus two votes.*
- *Super majority thresholds (90%, 80%, 75%, two-thirds, and 60% are common).*
- *Simple majority (>50%).*
- *Executive committee decides.*
- *Person-in-charge decides.*

The best thing you can do for your fellow, next to rousing his conscience, is not to give him things to think about, but to wake things up that are in him...to make him think things for himself.

—George MacDonald

result in a group maintaining cohesion and trust due to each member being equally affected by the successes and struggles of the group. This model can work quite well for small groups, but it is not the most effective means for decision making in large groups, a notion reflected by fungal networks.

When a mycelial network is small, all of its hyphae grow together on the same substrate and defend against the same attackers. But when a network grows quite large, its various hyphal branches no longer perform the same functions. This is because it is inefficient for a hypha to produce enzymes or antibiotics that it does not need. Regardless of how hyphae are acting in other branches of the network, each hypha must be afforded local autonomy to make the best decisions for its immediate needs. This is the most efficient use of the network's resources. Though each hypha and hyphal branch does connect to and communicate with the rest of the network, they are not entirely held to the demand of the entire network at all times. When a major issue arises that calls for increased assistance and aid, hyphal branches can alter their actions to support others and the network at large. But this is only called on when necessary.

Applying this perspective to human groups, one finds that for large assemblies, the most fungally-reflective model for decision-making is representative democracy. Under this system, individuals would be sent from smaller groups (hyphal branches) to the meta-group (mycelial network) where they would represent the needs of their respective group. To be truly representative, these individuals would need to be completely transparent and accountable for their actions and easy to replace should their actions go against the needs of the hyphae they represent.

In many instances, it is more efficient for individual hyphae to make their own decisions without having to always seek approval from their local branch or the whole network. The same goes for Radical Mycology groups or whole societies. Each person has the right to make the decisions that lead their life where they desire to grow. The goal of any network should be to support the desires of individuals and affinity groups of hyphae, while ensuring that their autonomy and resilience are not impeded, whether in the soil or in the streets. However, as any hypha's action can negatively affect the rest of the network, it must be accountable to those with which they work, lest it lose access to resources.

Enzyme Production: Other Skills

The following additional skills and/or topics of study can dramatically increase the effectiveness of a Radical Mycology group. Tackle them at your own pace, if at all.

- **Science:** Organic and inorganic chemistry, biology, ecology, hydrogeology, bacterial remediation, phytoremediation, and permaculture skills will improve the quality and longevity of installations.
- **Media:** Taking good photographs, making a short documentary, creating audio interviews, setting up a group blog, or writing compelling press releases, zines, or articles are all helpful skills for raising awareness and support around your projects. A brief study of graphic design can help create more effective and engaging educational materials.
- **Health and safety:** Haz-Mat, first aid, herbalism, and conflict mediation skills.
- **Fundraising:** A grant writing and/or business planning course for ambitious goals.
- **Organizing:** Various systems exist for improving time management and being less stressed. The book *Getting Things Done* by David Allen is a popular option.[7]
- **Legal:** Taking a basic "Know Your Rights" class will also help you tackle any police confrontations, wherever they arise.

Building Connections, Alliances, and Support

Once a group is established, its capacity for continuous growth will depend on the number and strength of the connections it forms in the community. Branching out and finding new members largely depends on the group's ability to maintain a consistent and reliable presence in the community and in ensuring that new members can easily get involved. By maintaining accountability and following through on commitments, groups can also come to build strong relationships and symbioses with other organizations and networks in their area.

Members will undoubtedly rotate and numbers may be low at times. In anticipation of these inevitable moments in volunteer organizations, a core group of members should be identified early on to ensure that the group maintains a degree of consistency over the long term.

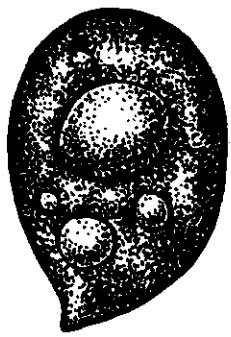
At the same time, it is important that groups ensure their members do not feel overwhelmed by their work. Just as mycelium branches throughout the growing season and rests in the winter months, so too should group members find time to slow down, practice self care, and take time to reflect on their accomplishments. This can be facilitated by rotating roles as well as by increasing the number of active group members. To minimize the need for having to bring new members up to speed in the middle of a normal meeting, set aside an hour once a month to orient new members, ideally before a normal meeting begins. And if a group ever weans in its energy inputs, it may be a good time to form a sclerotia and go into a resting phase until new nourishment avails itself.

However, when a group's network is firmly established it can branch out and expand its role within the larger community. The skills of mycology readily support efforts that are focused on environmental issues, non-fungal bioremediation, food security, building a local economy, permaculture, or survival skills.

By sharing skills and resources, Radical Mycology groups can actively support the growth of alternative social models that do not rely on mediation in the form of capital exchange. Through mycology, Radical Mycologists can actively perform acts of mutual aid that work to benefit the health and resilience of a community. This is witnessed not only in the small acts of mushroom growing, but in the larger insporation that comes from actively creating new ecosystems that lead to a healthier world.

Liberating Spores

Once the infrastructure of the group is in place, the goals outlined in the initial meetings can be effectively achieved. Radical Mycology groups have much to offer their community. The challenge for a group is to identify which needs are most pressing and also the most obtainable. Below are just a few suggestions of the many types of Radical Mycology group projects.



Increase Community Resilience

- Create edible, medicinal, or guerilla mushroom installations at community gardens, food banks, Food Not Bombs[8] locations, food justice organizations, or elsewhere.
- Work with food justice organizations to educate individuals and families on the benefits of growing fungi.
- Teach workshops on medicinal grain spawn production using liquid culture techniques.
- Build alliances with, and offer mycological support to, local Indigenous communities. Offer to help perpetuate traditional practices with fungi or share skills on

mushroom/lichen identification, mushroom cultivation, and bioremediation.
- Develop and maintain a local fungal culture library and/or spore bank to preserve genetics.

Support Local Ecologies

- Organize forest surveys to search for threatened mushroom and lichen species. Use these surveys to support campaigns for forest protection and to contribute to species distribution maps through Mushroom Observer and the North American Mycoflora Project.
- Safely and thoroughly design and install remediation projects with native fungal species and strains and other supporting organisms.
- Increase species diversity and redundancy by spreading fungal spawn in every nook, cranny, and shady spot of town.

Recompose Organic Waste

- Develop relationships with local coffee shops. Use their spent grounds to grow mushrooms. Give these mushrooms to local food banks or shelters.
- Remove invasive plants to clear land for a community garden. Use this plant material as a mushroom substrate to build topsoil and compost for the garden.
- Provide local businesses, food co-ops, and schools with cardboard and coffee digesters to create free spawn for the community.
- Glean agricultural waste from local farms to use as substrate.
- Create relationships with local mushroom farmers and glean spent blocks, unmarketable mushrooms, and other waste streams. Use these products to make medicines or create remediation installations.
- Adapt local mushroom species to local waste streams to produce spawn and mushrooms while creating highly resilient and closed-loop food systems.

Case Study: The Olympia Mycelial Network

Growing from the 2011 Radical Mycology Convergence, the Olympia Mycelial Network (OMN) in Washington state has worked for the last five years to share mycological knowledge with its local community. Some of the many organizations that the group has worked with include the following:

- **Olympia Free Herbal Clinic:** This organization provides herbal medicine to anyone for any donation rate, including zero. In 2013, the OMN installed medicinal mushroom species in their garden.
- **Garden Raised Urban Bounty:** This organization teaches at-risk youth how to farm and also provides free raised-bed gardens to low-income families. In 2014, the OMN provided various installations to GRuB, including a King Stropharia mother patch to serve as inoculum for the gardens of GRuB clients.
- **Olympia Food Co-Op:** In 2013, the OMN helped maintain parking lot water treatment systems with fungi as well as install various edible and medicinal mushrooms throughout the Co-Op's garden.
- **Media Island:** Birthplace of Indy Media and home to various social justice organizations in Olympia as well as several edible mushroom patches.

To learn more about the OMN, visit www.olympiamycelialnetwork.wordpress.com.

Case Study: Bay Area Applied Mycology

By Joseph Soeller

In 2011, Bay Area Applied Mycology (BAAM) formed from a group of people interested in taking their knowledge and passion for mycology out of the lab and into their local ecosystem. Since then, we have done several major projects in the San Francisco Bay Area, as well as hosted several cultivation workshops. Some highlights of our work include:

- Inoculating felled non-native Monterey Pines with native Oyster spawn to promote rapid decomposition and help suppress fire danger. This effort is part of a larger project to return a watershed to its natural oak savannah ecosystem.
- Growing living fungal filters using Oyster and King Stropharia mycelium to understand the logistics of partnering with large batches of mycelium, as well as integrating them into landscapes effectively.
- Using Chanterelle spore sprays to inoculate oak seedlings for savannah habitat rehabilitation.
- Developing an open access community mushroom lab in Oakland, CA. For a small monthly fee, BAAM members can access the lab and its tools. Located at Counter Culture Labs, a community science and art space within the Omni Commons of Oakland, the BAAM lab provides users with a sterile flow hood, inoculation tools, and several pressure cookers for both personal and group projects.

As a registered non-profit, BAAM is working to increase its impact in the Bay Area and beyond. Our mission is to achieve healthy ecosystems through the application and advancement of mycological and other biological processes. Future plans include eucalyptus decomposition using native Chicken of the Woods mycelium and studying the remediative capacity of various fungal species and strains on oil and plastic.

For more information, visit www.bayareaappliedmycology.org.

Regenerate Disturbed Habitats and Mitigate Pollution

- Adapt local fungal species to soil contaminants. Grow large quantities of this fungus and provide the spawn to local community members and organizations for remediation installations that you train.
- Install mycelial sorbtion systems in parking lots to reduce pollutant runoff into storm drains and local water systems.
- Develop strains that can remediate the wastewater of community art spaces.

Education and Outreach

- Lead urban mushroom and lichen forays. Discuss the impacts of pollution on lichen populations while noting the abundance of wild food and medicine that can be harvested in urban areas. Document species distribution.
- Hold educational and awareness-building events to address local issues of pollution concern or illegal polluting practices by industries.
- Teach workshops at schools of all ages at your local Free Skool. Children love to play with mushrooms and watch their mycelium grow. Learn by teaching.
- Perform street theater or hold a puppet show around topics in *Radical Mycology*.
- Table at community events and local mycological society gatherings.

Group Building Activities

- Hold art parties to create fungi-themed and fungi-based artwork.
- Host a mushroom-themed potluck.
- Go mushroom hunting together to study fungal ecology, collect specimens to culture, and to harvest food and medicine.
- Organize group trips to mushroom farms to learn about the industry. Seek out internships for members.

Internal Logistics and Support

- Highlight successes with a website and email list.
- Hold parties to celebrate successes.
- Plan mycofundraisers such as secret cafes, silent auctions, house parties, music shows, or performances.
- Build connections with local labs, public agencies, and universities to receive reduced or free testing of soil and water samples.
- Seek out elder mycologists and social organizers to serve as mentors for the project's growth.

Morning circle at the Radical Mycology Convergence, a volunteer-run event centered on sharing beneficial mycological information.

Sharing Fungi With Children

By Maya Elson

Sharing fungi with children is one of the most fun, fascinating, and fulfilling things I have ever done. By sharing my passion for fungi, I can help kids understand a wide range of topics including fire ecology, ecological succession, permaculture, and chemistry, as well as environmental issues such as pollution, logging, and climate change. Through a basic understanding of mycology, it's amazing to see how kids can connect the dots between themselves and all the members of their ecological community.

Many educators use worksheets, textbooks, and tests to study mycology. And though there is some value in these tools, studying mycology is also an incredible opportunity to break out of the box and get experimental in one's teaching process. Fungi are both fun and engaging, so why shouldn't our teaching be? By helping kids use different parts of their brains, move their bodies, do hands-on activities, and explore outside, not only will kids be happier, but they'll learn more. Whether you're playing with a couple of kid friends, or teaching a whole class, there are endless ways to connect kids with fungi. The following are a few of the projects and teaching lessons that I commonly use in my work as an outdoor educator.

General Suggestions

When you begin to share the beauty of mycology with children it is helpful to start with a spore of inspiration: a hook, or something they can relate to. Collect beautiful or bizarre looking mushrooms, mycelium, things you've made or dyed with fungi, mushroom books, or even just share a story about your own experiences with fungi.

I like to ask questions to get them thinking and talking about fungi. Some of my favorites are: Did you know there's hundreds of types of hidden fungi growing around us all the time? Did you know mushrooms can help clean up pollution? Who's seen a cool mushroom before? Did you ever wonder what makes a mushroom grow? You don't need to answer all these questions right away, just talk about it enough to get them curious. Try to connect fungi to their current understanding of the world and the things they care about. Topics from Chapters 1 and 2 of *Radical Mycology* can be taught while going on a hike or they can be interspersed with other activities. Tell stories, play games, get them to use their bodies and all of their senses. Find ways for them to smell, touch, see, and even hear the mushrooms. The more they feel personally involved, the more they'll connect with the fungi. Remember to ask questions and see if they can make mycelial connections with whatever information you've given them.

Safety

Many outdoor education programs have policies against teaching edible mushrooms to kids, and it's important to know this before delving in. However, I would rather share my knowledge on how to be safe when working with fungi than avoid them. In life, staying away from danger isn't always possible and trying to scare the kids away may even entice them to get closer—a rebellion with a potentially dangerous outcome.

With kids you don't know well, I suggest focusing your teaching on fungal biology and cultivation, as opposed to wild edible mushrooms. To avoid the risk of an accidental poisoning, it's safe and simple to just have a policy not to allow kids to harvest their own edible mushrooms without the guidance of a responsible adult.

Mushroom safety includes safety for the fungi and their ecosystem, too. Together with the children, observe the influence of humans on fungi and think about why some species only grow in certain areas. Teach and encourage the use of ethical harvesting practices, as described in Chapter 4, before a foray begins.

With kids that I have a trusting relationship with, and who I know are responsible, I have a mushroom test: before they can harvest or eat any mushroom, they have to prove to me they can

correctly identify, and sustainably and safely harvest the same mushroom four times. After that, it can be added to their mushroom list, but they still have to check with me before bringing any mushroom home to eat. Harvesting safely includes going through the ID process thoroughly, harvesting ethically, asking for help when they're unsure, and double or triple checking with books and with me. I also check in with their parents or guardian and help them to identify the mushroom species before letting their kids eat anything they've harvested. Don't be surprised if some parents are more receptive to the idea than others.

If you wish to involve kids in a remediation or restoration project, be sure to assess the project's risks as outlined in Chapter 10. Though the danger of a remediation project varies by site, in general I think such experiments are better suited for older kids who can be trusted to follow hazardous materials protocols. Consider preparing a water filtration or mushroom gardening project where they can get their hands dirty instead of one that involves toxins.

Cultivation with Kids

Eating mushrooms that you've grown is a fun and exciting activity for any age. It gets us to think like a fungus and tune in closely to these incredible beings. However, gaining a substantial yield requires time and equipment that busy educators may not have. Before initiating a cultivation project, it's important to ask yourself what you can do given your group's abilities, interests, location, and supplies. Try to find a way that each kid can be involved, keeping in mind that they may have to take turns. It's also important not to get your own or the kids' hopes up too high in case the mushrooms don't fruit. I like to emphasize just creating the conditions for fungi to grow, and if you get a moldy surprise, that's cool too! Simply watching mycelium grow and observing signs of decomposition can be a really fascinating experience.

Along with the various projects listed in Appendix J, children can be introduced to mushroom cultivation alongside habitat restoration efforts. For example, if you're studying birds, the water cycle, or plant ecology, you can pull invasive plant species in order to improve bird habitat, enhance the soil's ability to provide water for plants, and help native plants survive. You can then use the plants that you pull as a substrate for growing mushrooms.

Acting Out the Story of the Fungi

Most kids love to perform and watch plays, and making up mushroom plays are especially fun. With you as the narrator, kids can demonstrate concepts of nutrient and water cycling, food webs, mycorrhizal fungi, fungal reproduction, and more. If you have ample time, you and the kids can write a script.

Demonstrating how fungi help with decomposition is a quick and fun play. I like to begin by explaining what a saprotrophic fungus is and talking about nutrient cycling with the Sun, the source of energy on our planet. Ask a volunteer to stand on one side of the stage and say, "I am the Sun, I send energy to the Earth". Then have another volunteer be an Oak tree that says, "I am an Oak tree, I eat sunlight but I'm getting very old..." before they fall over and die. Another person can then act as an Oyster mushroom that comes in and says, "I eat dead plants and help turn them into soil." Another kid can then act as a new tree that's able to grow in the soil that the fungi made. Then you can have squirrels come and eat the mushrooms and drop their spores by another tree. If you have more time, you can add in mammals, insects, other fungi, microbes, and other players in the process of decomposition. It helps to have an assistant that whispers to each actor their role while you talk to the audience. If you think it might get confusing, consider re-starting the play from the beginning each time you add a new role.

Fungal Scavenger Hunt Items

- A squishy mushroom
- A stinky mushroom
- A mushroom that's an interesting color
- Mycelium
- Evidence of an early decomposer
- Evidence of a late decomposer
- A mushroom that grows on or near oak trees
- A redwood tree that is decomposing
- A mushroom with gills
- A mushroom that is partly eaten

Fungal Scavenger Hunts

Fungal scavenger hunts are a really fun and interesting way to get kids out in Nature, asking questions, flipping over logs, and exploring and observing fungal diversity on a new level. If you want to let them hunt on their own, make sure you define clear boundaries and pick a meeting time and

place for the end of the hunt. During the hunt or after you can ask questions like, "How long do you think it will take for that oak tree to be fully decomposed? How does that time span compare to conifers?" The suggested scavenger list is for central California, but can be adapted to include the plants in your local ecosystem.

Watch a Log Rot

The simplicity of this activity is part of its beauty. Find a log that fell a few months earlier and place it in a location where is will stay moist and easy to observe. Each week, you and your kids can make observations of the log and note how it changes over time. Keep an eye out for cool bugs and the animals that eat them, then ask the kids how fungi are helping increase the presence of these animals. This can be a valuable lesson in understanding the way fungi and other organisms co-create habitats. Be sure to check which species of fungi come and go as the succession of decomposition occurs. I recommend using a hardwood log, as they decompose more quickly and create habitat for lots of interesting decomposers. Alternately, you could do a comparison between a hardwood and conifer log.

Fungi are Everywhere

Decaying fungi can be easily observed growing on almost anything moist and carbon-based. One way to demonstrate this concept, suggested by my friend William Goss, involves poop, a substance kids tend to get excited about. Simply place a paper towel on the bottom of a clear, small vessel then place a small piece of semi-fresh horse (or another animal) dung on top. Add a little water to the paper towel twice or so a week to keep the dung from drying out. Then make surveys of the fungal diversity each week, noting how it changes over time.

A similar experiment, which could be done in tandem, can demonstrate that coprophilic fungi respond to light. For this project, place the dung inside of an opaque box, poke a tiny hole in the box's side, then cover its top. In a few days, you should be able to see some interesting Zygomycetes growing on the dung. And if you look carefully, you can see that they're shooting spores straight towards the light coming through the hole.

Another experiment is to open sterile petri dishes in several indoor and outdoor locations for 30 minutes to 12 hours. Then observe the fungal diversity and abundance that develops on the plates. You can do the same with pieces of fruit or bread that you seal in a plastic bag.

Mushroom Movements

Embodying the life cycle and roles of fungi through physical movement can be a great way to somatically understand them. A great way to do this is to ask your group to stand in a "fairy circle" where they will learn the parts and types of mushrooms using their own bodies as the mushroom. For example, they can put their hands together over their head to make a mushroom cap, or place their hands in their armpits or lower to represent different types of gill attachment. My friend Mitra Sticklen wrote this mushroom body song that is fun for kids and silly adults (sung to the tune of "I'm a Little Teapot"):

I'm a little mushroom, I'm your type!
This is my cap (both hands on head) *and this is my stipe* (both hands on legs)
When I grow up big and tall (start squatting and rise up with arms rising up from the ground to the sky)
All my spores will start to fall! (sprinkle fingers down like it's raining spores)

Fungal Arts and Crafts

Many of the skills presented earlier in *Radical Mycology* can be turned into fun activities for kids. Spore prints can be made on fabric and the children can draw designs around them. Try dyeing hair or clothes or making paper with mushrooms or lichens. Drawing or sculpting mushrooms and

their habitats will increase any learner's understanding of what they see and can help them focus on small details that are important for identification. With a cardboard toilet paper roll, a paper plate, some tape and some paints, kids can make unique mushroom sculptures and then watch them decompose.

Writing Exercises

After kids learn some fungal biology and ecology, writing exercises can be given to help reinforce and expand their understanding. The following exercises were designed by Mitra Sticklen:

- Using the letters from the word MUSHROOM, write out a line for each letter. Tell a story about a mushroom.
- Looking at photos or actual mushrooms, find one you like. This mushroom has been through a lot in it's lifetime! Write about the reasons you like it, and write about what you can see with your eyes and smell with your nose. What else would you like to know about this mushroom and its story?
- Imagine yourself as a fungus! Write a short story from the point of view of a fungus in which you try to answer the following questions: Where do you live? What do you like to eat? What do you observe in the environment around you?

The Sex Life of Mushrooms

By Willoughby Arevalo

Mushrooms are temples of sex, pure expressions of sexual potential, and a devotion to spore liberation. The mushroom lover's fascination with fungi may have a deep-seated, conscious or unconscious connection to the primal energies embodied by these fleshy, fertile fructifications. Fungi express brilliant sexual diversity in their forms, partnerships, spore dispersal methods, life histories, and mating types. And, if one studies them closely, they also provide a model with which to compare the sexual instincts of humans and to reflect on social constructions of sex, gender, and family. The following essay attempts to shed light on just a tiny portion of fungal sexuality, focusing on the life cycles and sexual diversity of mushroom-forming fungi and using metaphor with the hope that we can learn something about ourselves along the way.

A Mushroom Life Cycle

Imagine a spore drifting on an air current—a miniscule propagule at the mercy of the breeze, looking for a home. If it gets lucky and finds itself somewhere dark and wet, it can germinate. Whipping out its germ tube to penetrate its surroundings, the hypha ramifies its substrate, branching repeatedly, going both ways, touching itself, and anastamosing. With sensory molecules all over its body, it is in a constant state of arousal. In this adolescent stage in its life, the fungus' main concerns are eating lots of food, resisting competitors, and searching for a mate.

This primary mycelium is a swinging single cruising the underground and flirting by wafting off pheromones. In the mycelium of mushrooms, there are no physical differences between mating types and no specialized sexual organs; they rely solely on chemical courtship to sense with whom they are or are not compatible.

The pheromones fungi use can be very similar, or even identical, to those produced by humans and other animals, and the pheromone receptor protein molecules they use are similar to those we use for our senses of sight, taste, and smell.[9] Across kingdoms, humans and fungi still share some of the fundamental ways of noticing and evaluating potential mates, a likely relic of a common ancestor. This gives some insight into why the smell of some mushrooms can cause a tremor in the pelvic floor or why truffles are some of the most expensive foods in the world.

Upon pheromone reception and mutual consent, the hyphae of two compatible mycelial net-

works will fuse, their separate bodies now becoming one. This love connection can occur in a variety of positions, including tip-to-tip, tip-to-side, tip-to-peg, or peg-to-peg.[10] Their nuclei, functioning like the brains of their cells, migrate through each other's filamentous bodies, duplicating along the way, until each cell contains (typically) two nuclei, one from each primary mycelium. As with slugs, the different mycelia in a given partnership will both fertilize and be fertilized by each other, each playing both the "masculine" and "feminine" roles. In rare cases, such as in the hybridizations between some *Pleurotus* species, the fertilization will only go one way, with one partner being unable to receive the nuclei of the other.[11]

This process of dikaryotization begins a life partnership, a state of perpetual lovemaking where decisions are made collaboratively and work goes toward the growth of the whole. It takes a lot of work to establish a life-long relationship, but once it is complete, the two will grow outward together with more vigor, adaptability, and resilience than before. Some partnerships last for eons, while others are more ephemeral, unstable, and non-proliferative, just like so many human relationships.

Relationship Structure and Sexual Orientation in Mushrooms

While the pairing of two, sexually compatible partners is the most common relationship structure, it is not the rule. Not all Basidiomycete relationships are monogamous or capable of producing offspring. Occasionally, a partnered mycelium will invite in another mycelium, forming a triad. Two pairs of hyphae can also fuse to produce four-partner relationships, with each nucleus contributing its genetic knowledge and abilities to the healthy functioning of the system. This fungal version of polyamory, known as a polykaryon, can go on to create strong relationships and healthy offspring.

Sometimes, a fusion occurs between partners who are somatically compatible, but infertile. This is analogous to homosexuality in humans. These dikaryons can live together indefinitely, leading healthy lives. Without expending huge amounts of energy on reproduction, they have all the more life force to channel into their work of decomposition, symbiosis, or parasitism. These seemingly alternative family structures may lead us to question how the concept of family is constructed by our societies.

Once a partnership is committed and the mood is right, the mycelium begins to build mushrooms—its phallic and/or vulvic altars of copulation. The mycelium initiates by gathering primal energy into hyphal knots: tight, firm nubs of mycelium. As they expand, the developing primordia are pumped full of cytoplasmic juices. They elongate and expand, becoming engorged with fluid. As a fruiting body ripens, it develops a fertile hymenium, a layer of swollen hyphal tips. Just as the genitals of mammals look different from one species to the next, these tender bits adorn a spectrum of elegant forms, such as gills, tubes, teeth, veiny ridges, and mazes.

Here in the swollen basidium, on the fertile undersurface of the mushroom, is where the partnership is consummated. The two nuclei finally touch and merge, the climax of their tantalizing, life-long love affair. Their vital juices mix and mingle, resulting in a new generation of spores that emerge to perch on the exterior of the basidium. In order to hitch a ride on the breeze, the spores need to get off. Long ago in their evolutionary history, the Basidiomycetes developed an efficient and powerful way of liberating their spores: the mycological money shot of ballistospory.[12]

With a succession of new basidia taking the place of spent basidia, a mushroom sporulates repeatedly and perpetually throughout its prime. Tens of thousands of spores are ejected from a mature mushroom every second, adding up to copious spore loads. Sporulation researcher A.H.R. Buller estimated that an Artist's Conk can release roughly one-fourth its fruiting body's weight in spores over the course of a season. Do you release a quarter of your own body weight in gametes annually?

The Ecosexual Mushrooms: Gasteroid or Uteroid?

Of course, not all mushrooms get their spores off in the normal fashion. Many different strategies have evolved for spore dispersal in the large, diverse group of mushrooms referred to as the gasteroid fungi. They are so-called because these mushrooms produce their spores internally (*gastero* means stomach in Greek). But, really, what organism produces its gametes in its stomach? None. I propose that instead of perpetuating the term gasteroid, these fungi be referred to as *uteroid*.

It is thought that these fungi—which all evolved from fungi that once had a forcible spore dispersal strategy—developed their form to find a means for sporulating in conditions too dry for ballistospory. Whatever the reason, the results are tantalizing. These ecosexual fungi employ environmental forces and animals to get their spores off.

The uteroid puffballs and earthstars make their spores on basidia in an internal mass called a *gleba*, an ever maturing mass that is firm and juicy when young and becomes a soft, dry powder of spores at maturity. The gleba is encased in a membrane called a *peridium* (not to be confused with a perineum). At maturity, a mouth or slit called the *ostiole* forms at the top of the peridium. Like the os—the opening of the cervix in humans—the ostiole gives birth to progeny. However, unlike the uterus, the peridium lacks the muscle needed to contract on its own. A mature puffball lies in wait, in need of a gentle touch to help spread its spores. The impact of a raindrop or a falling twig provides enough force to release a puff of hundreds of thousands of spores into the air. A giant puffball of the genus *Calvatia* can contain trillions of spores.

Truffles and false truffles fruit underground, producing their spores in a solid, marbled mass of asci or on basidia in convoluted chambers, channels, and cavities. Lacking a mechanism for aerial spore dispersal, these fungi rely on animals to disseminate their spores. Once mature, they seduce creatures large and small by wafting off potent odors, often loaded with pheromones. The animals—ranging from insects, to rodents, to pigs, to people—sniff out the fungi, dig them up, and eat them, distributing the resilient spores in their droppings.

Stinkhorns are the mushrooms most associated with sex in the human imagination. Most are uncannily phallic in form, particularly those in the genera *Phallus* and *Mutinus*. Other species, such as members of *Clathrus* and *Psueodocolus*, are arguably more vulvic. Some members of the genus *Lysurus* embody elements of both. All stinkhorns feature a volva at their base.

A stinkhorn's development often begins in the dark of a warm, moist night, as a primordial "egg." The tip of the fungus splits through the peridium, lubricated by a clear jelly. The outer membrane remains as a volva engulfing the base of the hollow shaft, which rapidly engorges, becoming erect, exposing a swollen head toward the morning sky. Its upward thrust has been known to break through concrete. Fetid odors reminiscent of carrion, cabbage farts, green corn, or rotting crab emanate from the sticky, slimy gleba that coats the head or tentacles of these fungi. This stench is due to the presence of a number of volatile compounds, including formaldehyde and various sulphides.[13] The smell is an advertisement to flies, wasps, other insects and slugs, which all feast on the spore slime, track it around on their feet and spread it in their feces. Within hours of erection the gleba is all carried away, and the shaft—now spent—quickly becomes flaccid and putrefies.

Because of their shameless exhibitionism, stinkhorns are featured in folklore from around the world. In the Ozarks, there is an old belief that a girl who touches a fresh stinkhorn to her vulva will be lucky in love. In Borneo, a stinkhorn is regarded symbolically as the return of a dead hero's penis in spirit form. If you find your interest piqued by stories of the "pricke mushroom," a rummage through the mycolore will turn up a multitude of phalloid legends.[14]

Ascomycota: The Sac Fungi

Among other characteristics, the Ascomycetes are differentiated from the Basidiomycetes by their sack-like rather than club-shaped spore-producing structures. Certain species, such as some of the cup fungi and flask fungi, have fruiting bodies that are reminiscent of female sex organs. Their life cycles are diverse, encompassing unicellular and filamentous stages. Many species have an asexual orientation for most of their lives but may go through a sexual phase as well. The "Ascos" aren't as

quick to get hitched as the Basidios are. Rather than spending the majority of their life in a dikaryotic partnership, they linger in an extended courtship: the primary mycelia resulting from spore germination grow alongside each other without fusing, maintaining their independence until just before they are ready to mate.

When they do get it on, the two partners—one playing a role of active reception and the other a role of passive donation—form sexual structures called *gametangia*. The *gametangium* of the receiver (the ascogonium) penetrates that of the giver (the antheridium) with its tube-shaped trichogyne, sucking out its gametes and bringing them into the ascogonium where the fertilization ritual occurs. Genes are rearranged, and the resulting ascospores are packaged into a cylindrical sac—the ascus. The asci of many species are pumped full of water until the turgor pressure becomes too much to hold, the tip opens, and the spores are shot into the air in an explosive ejaculation.

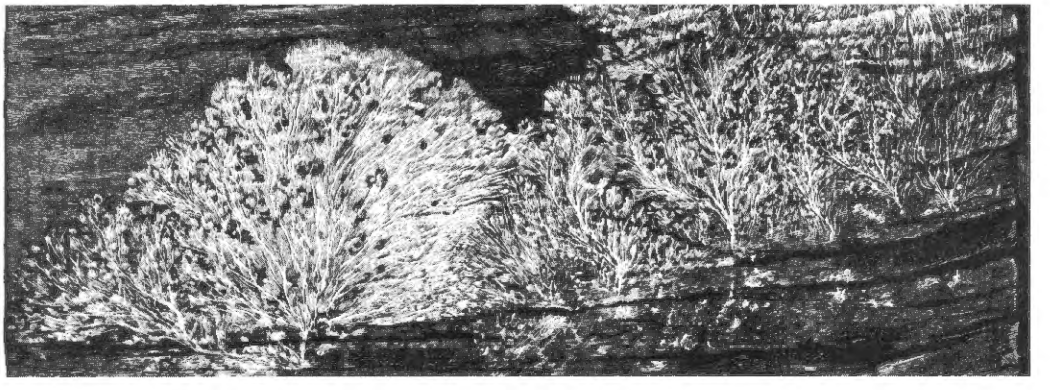
In the cup fungi, the asci often sporulate simultaneously with so much force that they create an updraft that is able to carry the spores away. A cup can release so many spores in quick succession that a human can hear a fizzing sound of the bursting asci and see a puff of spores arise from the cup like a wisp of smoke. This simultaneous climax can sometimes be elicited by a warm breath or a gentle caress from a finger, but only if the mushroom is ready and willing.

Mating Types, Sex, and Gender: Beyond Dichotomies

Mushrooms express a great diversity in mating systems. Though spores of most species tie the knot with others, some are self-fertile, packing two compatible nuclei into each spore. Some examples of these auto-erotic fungi are the cultivated Button mushroom (*Agaricus bisporus*), the Inky Cap (*Coprinopsis stercorea*), members of the genus *Laccaria,* and the bird's nest fungi. Relatively few mushroom species have only two mating types. The poster child for sexual diversity among mushrooms and role model for genderqueer fungophiles is the pansexual Split Gill fungus, which has 23,328 mating types. Any individual Split Gill mycelium is able to copulate with about 98% of all other members of its species.[15] This has allowed it to adapt to living in an extreme range of substrates and conditions and become one of the most common and widespread of all mushroom species.

Most human cultures hold a strongly binary perception of sex and gender. This reductionist view ignores the reality of intersexuality and transsexuality. Within our species there is a spectrum in biological sex based on variations in the morphology and combinations of internal and external sexual anatomy, hormone levels, and/or chromosomal variations. According to the Intersex Society of North America, about 1% of people are born with bodies differing from standard male or female.[16] Beyond biological sex, humans exhibit interpretations of the social construct of gender within a spectrum. Thanks to social movements and cultural shifts in some societies, self-realized gender identity is becoming more frequently expressed and less often repressed.

If we engage in nurturing and attentive relationships with fungi, they may lead us to a deeper understanding of how sexual diversity has facilitated their adaptation towards inhabiting innumerable ecological roles and niches. Likewise, through our connection with them, perhaps they can illustrate that the natural and beneficial nuances of life's expressions may be integral to our evolution as well.



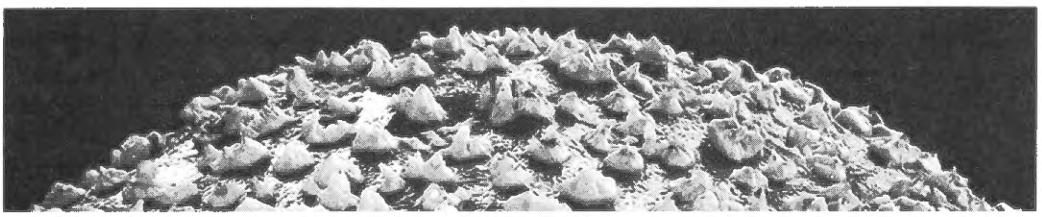
Chapter Twelve

MycoGnosis

Of all the forms of human-fungal relations developed throughout time, perhaps none is more controversial than the experiences countless societies have held with fungi that alter the human perception of reality. Indeed, psychoactive fungi have played a significant role in the cultural developments that led to modern forms of civilization. Yet today, taboos against accessing altered states have limited discussion on the importance of these fungi, whether historically or contemporarily. Many mycologists discover their fascination with mushrooms by experiencing these altered states, yet later become unwilling to admit these origins for fear of ridicule. In academia, the cultural influences of altered states and psychoactive fungi are essentially absent from courses in theology, philosophy, or anthropology, despite their wide-ranging and well-documented historical significance.

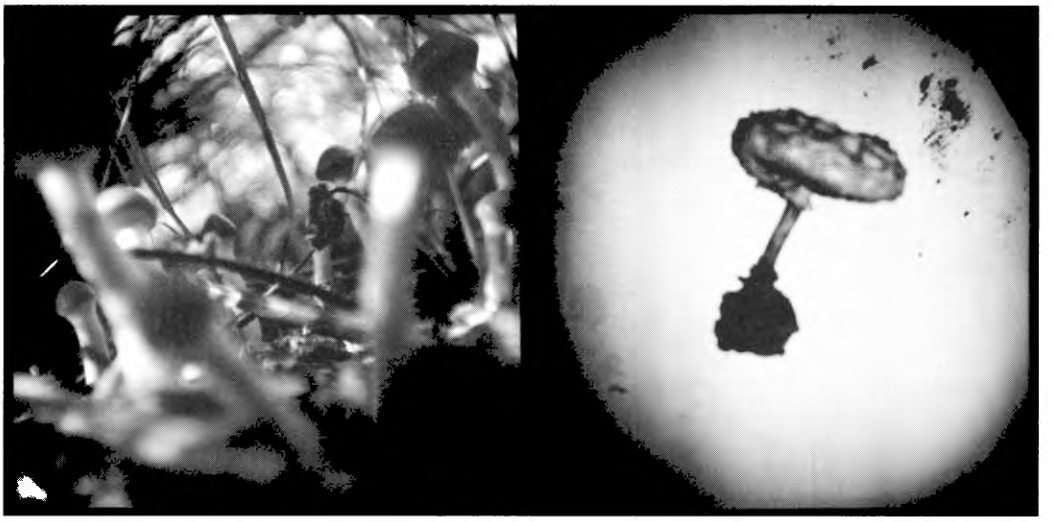
With limited resources being invested into an objective understanding of these fungi, documenting their history and implications has largely been left to the efforts of independent researchers. However, here too problems arise. Considering that many of these investigators are frequently passionate advocates for the use of these substances, their findings are often biased. Without sufficient peer review—as is found in other areas of pharmacology, anthropology, and sociology—much of the literature on psychoactive fungi has skewed toward highlighting their positive effects, while understating their pitfalls. When one adds in the range of opinions and unfounded claims about psychoactive mushrooms on the internet, the curious researcher into the topic is left to find a wash of conflicting data. The complexity of such a taboo issue thus becomes compounded, leaving the revelations of these fungi as distorted as the imagery they rise from.

For Radical Mycologists, the question of how psychoactive fungi can influence resilient people or societies is equally complex. Though much has been written about the positive potential for these fungi to guide cultural transformation, a review of their history also reveals that their consumption can be detrimental to a person or society working to redefine itself. To fully account for the unique traits that these fungi offer, all of these historical impacts must be assessed. Otherwise, false assumptions can readily be placed on the significance of these fungi, potentially with unforeseen and wide-ranging consequences. To develop the most positive relationship between humans and fungi in the present and coming years, this legacy must be understood by all who wonder if these fungi should be integrated into any state of development, whether it be a personal or cultural one.



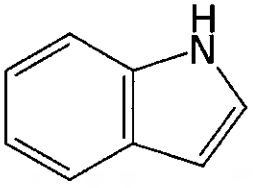
The Varieties of Psychoactive Fungi

The first step in studying psychoactive fungi is to clarify their forms, functions, and chemistry. Of the roughly 30,000 documented species of mushrooms, about 200 are known or suspected to be psychoactive. Most commonly encountered psychoactive fungi can be divided into one of two categories based on whether their active constituent is psilocin or muscimol. The psilocin-containing mushrooms are those most commonly used for contemporary practices and constitute the larger group of the two, while the muscimol-containing fungi have the richest global history.



Psychedelic Chemistry

Psilocin is one of the many *tryptamine* psychedelic compounds. As with all tryptamines, the central feature (or "backbone") of psilocin's chemical structure is a 3-(2-aminoethyl) indole, itself being a modified form of the essential amino acid tryptophan. Other tryptamines include the psychedelics DMT, 5-MeO-DMT, LSD, ibogaine, and bufotenin. The only chemical differences between these various compounds are slight modifications in the placement of elements or chemical groups around this indole. While these adjustments are slight, they make all the difference as each structure brings about its own characteristic effects in the user. The magic and mystery of psychoactive chemistry, then, ultimately falls on subtle shifts in the electrical signature of these simple substances.



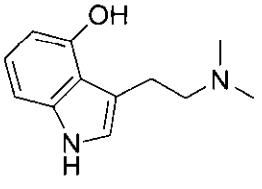
An indole ring is a dual-ring structure comprised of a benzene ring fused to a pyrrole ring. Compounds that contain an indole ring are often referred to as "indoles."

The *phenethylamines* are a separate class of chemicals that contain a large number of psychedelic substances. It includes many "designer" drugs (e.g. MDMA, 2C-B, 2C-I, MDA, Adderall, and mescaline, among others). Some phenethylamines can be biosynthesized from the amino acid L-phenylalanine. They tend to affect dopamine levels in the brain.

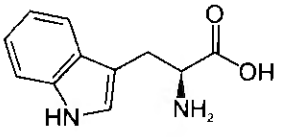
Psychoactive substances can also be classified by how they interact in the brain or by their typical psychological effect on the user. These categories include the *dissociatives* (e.g. DXM, PCP, ketamine, and nitrous oxide), the *empathogens* (e.g. MDMA and 2-CB), and the *cannabinoids* (e.g. THC and CBD). A number of other psychoactive substances have unique chemical structures and/or effects that cannot easily be placed into the above categories. These eclectic compounds include salvinorin A and B, atropine, scopolamine, harmaline, ibotenic acid, and muscimol.

Psilocin *(sil-o-sin)*

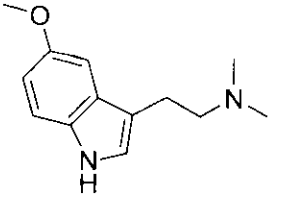
$C_{12}H_{16}N_2O$
4-OH-DMT
4-hydroxy-N, N-dimethyltryptamine
4-hydroxy DMT (i.e. DMT with a hydroxyl molecule at the 4-position)



L-Tryptophan



DMT



Psilocin

Psilocin-Containing Fungi

Of the roughly 180 species of fungi that contain psilocin, most are in the genus *Psilocybe*. Psilocin-containing fungi are found on every continent except Antarctica. Mexico hosts 75 psilocin-containing species, the greatest number of any country. Fifty-three of these are *Psilocybes*. On the black market, *Psilocybe cubensis* dominates due to its ease of cultivation on a variety of simple substrates.

Over a dozen other genera are said to contain species with psilocin and/or the related compound psilocybin. All of the psilocin-containing species are decomposers; some inhabit grasslands and lawns, while others prefer riparian areas, animal dung, or the wood chips in manicured gardens and landscaped areas.

Psilocybe Species Distribution[1]

Mexico: 53
US and Canada: 22
Australia and Pacific Islands: 19
Europe: 16
Asia: 15
Africa: 4

The (Bio)Chemistry of Psiloc(yb)in

While psilocin is the main compound responsible for the effects of these mushrooms, four other active compounds may be present, depending on the species: psilocybin, baeocystin, norbaeocystin, and aeruginacine. Regardless of species, psilocin and/or psilocybin are typically found in the highest concentrations.

Psilocin and psilocybin are closely related compounds, differing only by the addition of a phosphate group to the 4-position of psilocybin's indole ring. It is believed that this phosphate group protects psilocybin from oxidation, giving it the ability to remain stable at room temperature for years and to be boiled with minimal degradation. Psilocin, on the other hand, is very unstable due to its phenolic hydroxyl group, which rapidly degrades in the presence of oxygen. It is believed that when psilocybin is ingested it is quickly converted (dephosphorylated) to psilocin in the digestive system, kidneys, liver, and perhaps blood by means of alkaline phosphatases that remove the phosphate group.[2] Thus, it is psilocin, and not psilocybin, that reaches the brain to bring about the psychedelic experience. However, as psilocybin is easier to synthesize and store, it is more often referred to in the literature.

Many psilocin mushrooms stain a deep cerulean blue when handled, a reaction presumably attributed to the oxidation (degradation) of psilocin. In other words, as these mushrooms turn blue, their potency may be decreasing. Not all psilocin-containing fungi stain blue and many non-psychoactive fungi stain blue due to the oxidation or modification of compounds other than psilocin. For example, Satan's Bolete (*Boletus satanus*) rapidly turns blue when cut due to the presence of (the non-psychedelic compound) variegatic acid.

Baeocystin and norbaeocystin are two compounds that are chemically similar to psiloc(yb)in and trace amounts of them are often found in certain species of psychoactive fungi. Structurally, they are psilocybin with one methyl and two methyl groups removed, respectively. While these compounds seem to influence the effects of psiloc(yb)in, their individual actions on the body are not well studied. A fifth active compound, aeruginacine, is present in *Inocybe aeruginascens*. Its chemical structure has not yet been resolved, but it can be distinguished from the other four compounds using thin layer chromatography.[3] Other, unidentified psychoactive compounds may exist as well.

The different species of psilocin mushrooms have varying amounts of these five alkaloids and it is hypothesized that variations in their ratio corresponds to the distinct "flavor" of each species' psychoactive effect. For example, *Psilocybe cubensis* is said to create a more body-based, "earthy," or "muddy" experience, while *P. cyanescens* produce a mental, "cleaner," and "clearer" trip. In all species, the entire mushroom seems to be psychoactive, though studies have shown higher alkaloid concentrations in the caps of *P. cubensis* specimens.[4]

Metol (from photo supply houses) enhances the bluing reaction of psilocin. Mushroom pieces added to Metol dissolved in 20x its weight in water will turn dark blue-violet in 30 minutes.

A bluing reaction should not be used on its own to identify a psychoactive mushroom. However if that bluing mushroom also has purple-brown spores (as with Psilocybes*), it might produce psychoactive effects.*

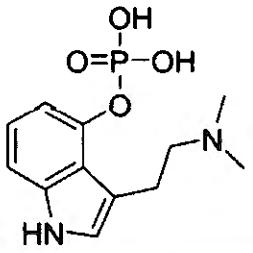
Psilocin mushrooms are some of the only natural psychoactive substances that are both orally active and produce strong effects in relatively low doses. In comparison, the powerful tryptamine DMT is found endogenously in many plants and animals yet is not orally active. When DMT is swallowed, a chemical in our stomachs (mono amine oxidase, MAO) quickly neutralizes this substance and prohibits it from being metabolized or producing any psychoactive effect. To be orally active, DMT must be mixed with a substance that inhibits this neutralizing compound (i.e. a mono amine oxidase inhibitor [MAOI] such as the harmaline found in Syrian rue [*Peganum harmala*] or the

harmine found in the ayhuasca plant [*Banisteriopsis caapi*]). It is believed that psilocybin is orally active due to the same phosphate group that keeps it shelf-stable. The oxygen atom at the 4-position of psilocybin's indole ring forms a weak hydrogen-bond with the nitrogen on the molecule's carbon "tail." This bond effectively blocks MAO from neutralizing psilocybin in the gut, thereby allowing it to enter the bloodstream and to ultimately be dephosphorylated and metabolized as psilocin.[5]

Like all tryptamines, psilocin is chemically similar to the neurotransmitter serotonin, allowing it to act as a partial agonist (i.e. it stimulates some neurons and not others) on the brain's serotonergic receptors $5HT_{2A}$, $5HT_{2C}$, and $5HT_{1A}$.[6] Serotonin receptors are found throughout the brain's cortex as well as in the raphe system, the thalamus, and abundantly in the locus coeruleus at the base of the brain. The locus coeruleus is considered a "novelty detector" that notifies the rest of the brain of changes in the environment and its stimulation seems to increase one's ability to process information.[7] More generally, serotonin receptor excitation has been linked to positive moods, increased motivation, memory, and learning. Serotonin is often said to be the "happiness neurotransmitter," though it is also responsible for many other emotions and physiological activities.

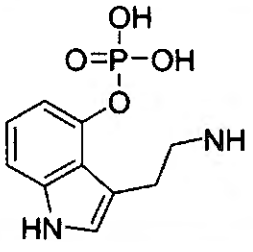
When psilocin activates these receptors, it produces various psychoactive effects. How this happens is not understood. While scientists have been able to show a relationship between psilocin and serotonin receptors, how consciousness is actually produced and modulated in the body is one of the biggest riddles in science and philosophy. As such, one should not assume that psilocin's effects are limited to simple brain chemistry—they may be much more complex than one can even imagine. Experiments using radiolabeled psilocybin have shown the substance to quickly become distributed throughout the entire body where its interactions are not well understood.

Psiloc(yb)in has not been shown to cause damage to the brain nor to any other major organ. Other than exhibiting a slight elevation in blood pressure with some users, the physiological effects of psilocybin are minimal with infrequent use. Psilocybin is not habit forming and is non-addictive. When taken in successive sessions, its effect rapidly decreases. While this increased tolerance wears off within a few days, in the short-term it disables the user from going on a mushroom binge. It is estimated that a 185-pound adult would have to eat 23.9 grams of pure psilocybin (or about 2,390 grams [5.3 pounds] of dried *P. cubensis* mushrooms) to die.[8] Based on the amount of psilocybin necessary to cause human death, this compound is less toxic than heroin, cocaine, alcohol, nicotine, caffeine, and aspirin. As far as I am aware, there is only one human death directly attributed to the consumption of psiloc(yb)in.[9]



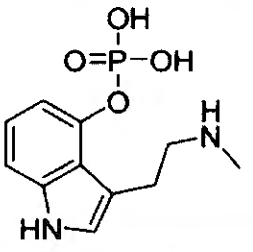
Psilocybin *(sil-o-sybe-in)*

$C_{12}H_{17}N_2O_4P$
4-OPO4-DMT
4-Phosphoryloxy-N,N-dimethyltryptamine
O-phosphoryl-4-hydroxy-N, N- dimethyltryptamine
3-[2-(Dimethylamino)ethyl]-1H-indol-4-ol dihydrogen phosphate ester



Norbaeocystin *(nor-bay-o-sis-tin)*

$C_{10}H_{13}N_2O_4P$
4-OPO4-T
4-Phosphoryloxytryptamine
1H-Indol-4-ol, 3-[2-aminoethyl] dihydrogen phosphate ester



Baeocystin *(bay-o-sis-tin)*

$C_{11}H_{15}N_2O_4P$
4-OPO4-MT
Desmethyl psilocybine
4-phosphoryloxy-N-methyltryptamine
3-[2-(methylamino)ethyl]-1H-indol-4-ol dihydrogen phosphate ester

Effects

Psilocin fungi can be consumed fresh or dried, whole or powdered, in a variety of food-based preparations, or their active constituents can be extracted. Fresh mushrooms are generally more potent due to the higher psilocin content. Dosages vary from 0.1–10+ grams of dried mushrooms depending on the species consumed and the user's experience and tolerance level.

Describing any "typical" experience of these mushrooms is not easy. While there are often similarities among the experiences of users, there is no guarantee that one's experience will be of a certain quality. Every person responds differently to their environment and has her or his own unique relationship with themselves. Both of these dynamics are heightened and modified on the mushroom trip. As such, it is not possible to know how exactly psychoactive mushrooms will affect a given individual. Further, attempting to describe the effects of psilocin may actually influence the user's experience on a subconscious level, something I find rather ethically challenging. As the personal significance and long-term psychological, emotional, and attitudinal impacts that can come from consuming these fungi can be life changing, describing—let alone working with—the power of these fungi should not be taken lightly. Factors that tend to influence a person's experience on psychoactive fungi include:

- The species and dosage consumed.
- Personal metabolism and chemical sensitivity.
- Preconceptions of drugs and psychedelics gained directly or indirectly from others.
- Personal experience with drugs in general, and psychedelics specifically.

- Personal belief systems, motivations, and life desires.
- The specific collection (psiloc[yb]in content can vary dramatically from harvest to harvest), method of preparation, and age of specimens.
- The "set" and "setting" of the session.
- Intentions and desires for the experience.
- Post-experience integration and processing strategy.

Average Dose Sizes of Psilocybe cubensis

Threshold: *0–0.25 grams*
Light: *0.25–1.0 grams*
Average: *1.0–2.5 grams*
Strong: *2.5–5.0 grams*
Heavy: *5.0+ grams*

Experience "Levels"

That said, it is helpful for the reader inexperienced with psilocin mushrooms to have a sense of how their effects are often described. Based on the above, I find it easier to separate standard dosages from the different intensity "levels" of experience one may have on any dosage.

- **Level 1** (*Spore*): Unusual bodily sensations (a body high) are felt and some mild visual enhancement is observed.
- **Level 2** (*Hyphal*): Greater visual enhancement coincides with the sensation that objects are alive. Creativity increases along with 2-D, closed-eye visuals.
- **Level 3** (*Mycelial*): Strong open-eye visuals (curving, warped, flowing, or kaleidoscopic patterns) and 3-D closed-eye visuals manifest. The physical senses and the sense of time behave unusually. Behavior regresses as childhood or other repressed memories are recalled. Empathy toward others is significantly heightened.
- **Level 4** (*Ecosystemic*): Very strong visuals coincide with the destruction or splitting of the ego. Communication with objects becomes possible as time loses meaning. Out-of-body experiences and/or E.S.P.-type phenomena are sensed.
- **Level 5** (*Universal*): All sense of an ego and any visual connection with reality is completely lost as the psilophile merges with objects and/or the entire universe. Accessing the akashik records/genetic database is reported. This level defies description.

Past Names for Psychedelics

Deliriants
Delusionogens
Eidetics
Hallucinogens
Misperceptonogens
Mysticomimetics
Phanerothymes
Phantasticants
Psychotics
Psychoticants
Psychogens
Psychosomimetics
Psychodysleptics
Psychotaraxics
Psychotogens
Psychotomimetics
Schizogens

Physiological changes such as increased heart rate vary by user and their state of calmness and agitation. Chewing the mushrooms thoroughly and holding them in one's mouth increase the rate of effectiveness, which typically begins in the first one to two hours. The peak of the experience can come on about two hours later, crest for one to two hours, and then taper off over another one to three hours. The whole experience often lasts four to six hours, with physiological aftereffects noticeable for up to eight hours afterword. Insights from the experience can linger for a lifetime.

But Why?

The mere fact that some fungi even produce these compounds is quite remarkable. Psilocin and its related alkaloids are considered secondary metabolites that are not crucial to the fungus' survival. Why do these fungi produce these compounds in such abundant quantities (sometimes in excess of 1% of the dried weight of the mushroom)? This question has never been adequately answered. Some argue that it is a defense mechanism, others say it is a spore dispersal strategy that attracts certain animals. Others suggest that the coevolution of psychoactive fungi and humans was and is an intertwined relationship and that these fungi have evolved to provide information to their human counterpart through unique means of communicating with Nature.

Some psychoactive species appear almost exclusively in areas of human settlement, leading to the suggestion that the trailing of these fungi into the landscapes of modernity are subtle reminders of the eternal potential to connect with Nature, regardless of context or constraint.

On "Bad Trips"

When an under-experienced user consumes a heavy dose or takes mushrooms in a non-conducive setting, the experience can quickly turn from an enjoyable one into a "bad trip." This phenomenon was so common in the early years of research that psychedelics were called psychotomimetics, meaning they mimic psychosis. A relatively recent study from 1998 compared the psilocin state to schizophrenia-like psychosis.[10] When a psychedelic experience turns bad, the trip commonly takes one of three main forms:

1. The user is forced to face unexpected emotional and psychological traumas buried in their psyche. While this is never pleasant, if handled and subsequently integrated correctly, the insights gained during this emotionally challenging experience may guide the user to seeking further healing in their sober state.
2. The user lacking cognitive discipline becomes susceptible to messages and objects in their external environment, with unknown consequences on their subconscious and future behavior. Subtle programming of belief systems can result while, in the event of the user being overwhelmed by dark thoughts, the entire experience can quickly turn into a frightening and traumatic event.
3. The user has an extreme loss of connection to reality, resulting in a psychotic breakdown. Such temporary psychosis can cause long-term psychological trauma that may persist for days, weeks, or years thereafter.

Muscimol-Containing Fungi

This group is primarily comprised of *Amanita* species, including the familiar red and white Fly Agaric (*Amanita muscaria*), the most commonly worked with muscimol-containing mushroom. Similar in appearance, *A. pantherina* tends to produce a much higher concentration of active compounds and, as such, frequently leads to a rather unpleasant and uncomfortable experience in people who unwittingly eat too much. All *Amanita* species are ectomycorrhizal. *A. muscaria* has had the greatest historical significance and, as such, will be the primary muscimol-containing mushroom referred to in this chapter.

The main active ingredients in *A. muscaria* seem to be ibotenic acid, muscimol, and muscazone. None are considered addictive. Ibotenic acid and muscimol are found in their highest concentration in the yellow region just below the cuticle (skin) of the mushroom cap. The most potent specimens have a red cap cuticle and are harvested in the spring or summer when their caps are fully opened. A fourth compound, muscarine, is not thought to be psychoactive but is attributed to the nauseating feelings that often accompany *A. muscaria* consumption.

Muscimol acts on GABA receptors in the brain and is considered an inhibitory depressant, attributable to the drowsy feelings associated with consuming *A. muscaria*. Muscimol increases levels of serotonin, dopamine, and acetylcholine, and decreases noradrenaline. Experiments on mice have shown it increases brain wave synchronization in different parts of the brain and produces unexplainable, yet characteristic spikes in brainwave activity. Muscimol has an LD_{50} of 45mg/kg when administered orally to rats.

Ibotenic acid is structurally similar to the neurotransmitter glutamic acid and acts on the same receptors in the brain, making it an excitatory agent. Ibotenic acid is also said to be somewhat neurotoxic due to the fact that experimental injections directly into the brains of mice have produced lesions. This chemical is believed to cross the blood brain barrier intact via active transport, though some of it converts to muscimol in the body via decarboxylation. Just as psilocybin loses its phosphate group to become psilocin, ibotenic acid loses its carboxyl group to become muscimol. A third active compound, muscazone, has also been isolated in *A. muscaria* specimens, though it is often found in negligible concentrations. Ibotenic acid has an LD_{50} of 129mg/kg when taken orally by rats.

Muscimol is often cited as the main active ingredient in *A. muscaria*, though its use in isolation has been said to cause experiences that are less "structured" when compared to consuming whole

The red pigment in the cap of A. muscaria *is called muscaflavin; it is also found in certain waxy caps species such as* Hygrophorus puniceus *and* H. cuspidatus.

The Life Cycle of *Amanita muscaria*

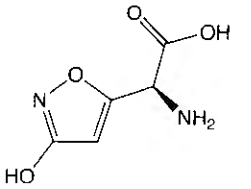
To fully appreciate some of the historical associations with this mushroom (discussed later), it is helpful to visualize the stages of its growth. The fruit body of *A. muscaria* begins as a small white egg which, when cut in half, displays the complete outline of the mushroom contained within this egg, or universal veil. As the mushroom "hatches," its bright red cap quickly rises on its white stalk. One half of the universal veil remains on the ground, cupping the base of the stalk, while the upper portion remains on the cap, fragmenting as the cap expands from a single piece of tissue into the mushroom's characteristic constellation of white spots. As the cap continues to enlarge, the partial veil covering the gills tears away and remains on the stalk as a prominent skirt. Eventually, the cap goes from convex to planar to upturned, forming a large cup of sorts in which rain and dew collect. This dew can be tinged red and even produce slightly psychoactive effects. As the mushroom passes maturity, it soon dies, falling back to the ground, surrounded by a ring of white spores on top of the mushroom's nest of forest litter.

mushrooms. Just as baeocystin and norbaeocystin seem to modulate the effects of psilocin, ibotenic acid and muscazone may influence the subjective effects of muscimol.

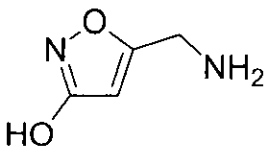
While the liver destroys muscarine, much of the ibotenic acid (and, to a lesser degree, some of the muscimol) passes through the kidneys intact. The resultant urine of the user is thereby rendered psychoactive and often takes on a scent, flavor, and pinkish color that is said to make the urine more palatable than normal. This palatability is known because, as discussed later, the urine of the user must be consumed to achieve the full effect of *A. muscaria*. It is said that the psychoactive urine can pass through the body five to six times and still produce effects in the user as more and more ibotenic acid is decarboxylated into muscimol with each pass.

The greatest risk in working with muscimol mushrooms is in misidentifying these fungi with their deadly relatives, especially the Death Cap mushroom (*A. phalloides*) and the Destroying Angel group (*A. bisporigera, A. virosa,* and *A. ocreata*). *Amanita muscaria* and *A. pantherina* have each been attributed to the death of an elderly person.[11]

Consuming the dried caps of *A. muscaria* is the most effective means of working with these mushrooms. Drying is important as it both dissipates the muscarine from the mushroom and converts much of the ibotenic acid to muscimol, thereby decreasing the nauseating potential as potency is increased. Three dried caps is a traditional dosage in some Siberian cultures. Taken orally, ibotenic acid is active at 50–100 milligrams and muscimol displays activity at 10–15 milligrams.



Ibotenic Acid



Muscimol

Amanita citrina, A. corthurnata, A. crenulata, A. gemmata, A. muscaria, A. pantherina, A. parcivolvata, A. porphyria, A. regalis, A. solitaria, A. strobiliformis, A. tomentella, *and* Tricholoma muscarium *contain muscimol. Various species of* Clitocybe, Inocybe, *and* Omphalotus *have also been reported to contain trace amounts of ibotenic acid and/or muscimol.*

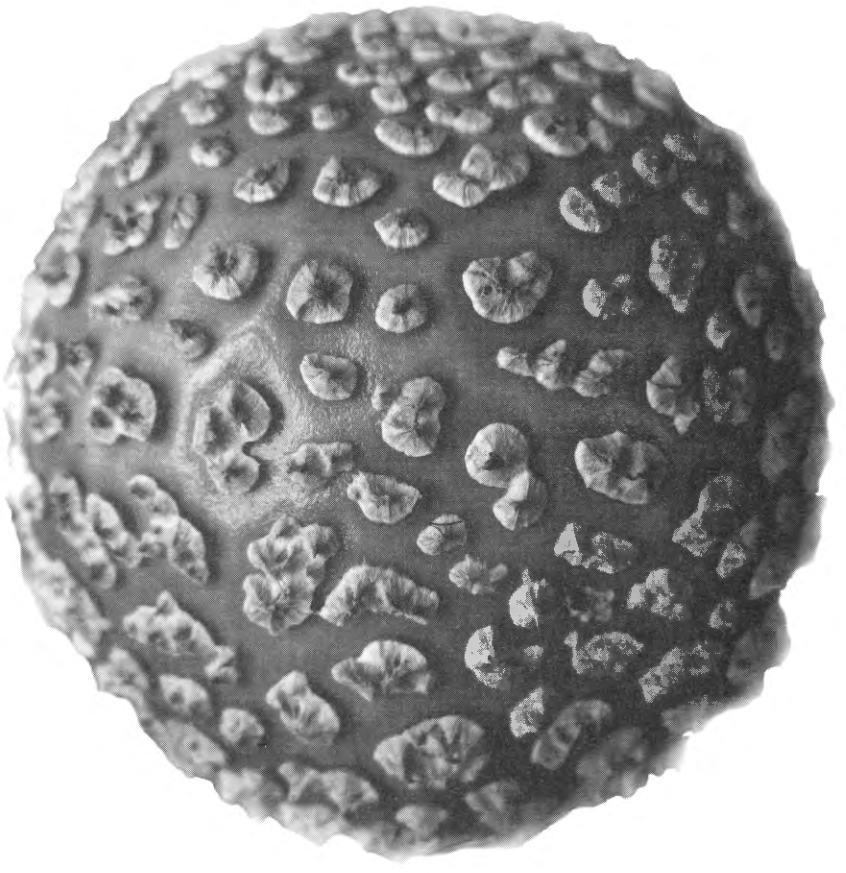
Dosage and Effects

The same words of caution in regard to describing the effects of psilocin apply to the muscimol experience. Below are average effects at various dosage amounts of *Amanita muscaria*:

- **Light:** 1–5 grams (approximately 1 medium cap)
- **Average:** 5–10 grams (approximately 1–3 caps)
- **Strong:** 10–30 grams (approximately 2–6 caps)

The effects of *A. muscaria* typically begins within 30–60 minutes. The peak occurs after about-two hours, crests for one to two hours, then tapers off over another one to three hours. The whole experience lasts five to ten hours with aftereffects noticeable for up to five hours afterward. Insights from the experience can linger for a lifetime.

The psychoactive effects of *A. muscaria* seem to be quite variable, especially if the user has not prepared or consumed them properly. Nausea, "drunkenness," confusion, lethargy, and deep sleep are some of the less intriguing effects commonly reported by users. However, when taken properly, the effects of *A. muscaria* are said to be entirely different from those of psilocin mushrooms. Some compare the effects of psilocin to an opening of the chakras that enables a greater amount of energy and information to enter and exit one's body. Muscimol, on the other hand, clarifies perception of the world, in contrast to the distortions of psilocin. On muscimol, physical items are witnessed objectively, without a mental projection, and their apparent size can be drastically affected, an effect known as macropsia. Astral projection, clairvoyance, telepathy, and direct communication with God/Spirit are not uncommon themes in the *Amanita* experience. Physically, great vitality is felt along with the sense that one can conquer the world, that one *is* a god. This mushroom was highly revered in cultures around the world and was consistently considered a god unto itself, a gift of heaven made manifest on Earth.



Other Psychoactive Fungi

Though the above categories comprise the bulk of the known and well-documented psychoactive fungi, several others are worth mentioning:

- Rätsch lists the following as psychoactive: *Hygrocybe psittacina, Naematoloma popperianum, Stropharia coronilla, Cordyceps capitata, Cordyceps ophioglossoides, Hydnum repandum, Gerronema fibula, G. solipes,* and *Psathyrella candolleana.*[12]
- Puffballs such as *Vascellum pretense* and *Lycoperdon candidum* may be psychoactive.
- Robert Rogers reports some *Coprinus spp.* (*C. narcoticus, C. radicans,* and *C. niveus*) may be psychoactive when fresh.[13] Rogers also lists *Mycena pura, M. amicta, M. cyanescens,* and *M. cyanorrhiza* as potentially containing psilocybin.[14]
- *Psathyrella candolleana* may contain psilocybin and psilocin.
- *Gymnopilus junonius* (*waraitake* or Big Laughing Mushroom) contains psilocybin as well as bis-noryangoin, an analogue of yangonin, a psychoactive substance in kava-kava.
- *Laetiporus spp.* have been reported to be psychoactive.[15]
- *Scleroderma citrina* is reportedly a narcotic.
- Various *Boletus* and *Russula* species of Papua, New Guinea are used for psychoactive effects.
- Ergot (*Claviceps spp.*) is a fungal pathogen on certain grasses and contains LSA, a tryptamine similar to LSD. But, as other compounds in the fungus can be fatal, consumption of Ergot is not advised.
- Endophytic *Acremonium spp.* found in "Sleepy Grass" (*Stipa spp.*) can supposedly cause psychoactive effects in humans due to the presence of LSA. Robert Rogers suggests 1 milligram of the fungus for a 150-pound adult.
- A psychoactive basidiocyanolichen from the genus *Dictyonema* is used by the Waorani people of Ecuador. The lichen is mixed with unidentified mosses and made into a tea that is drunk for psychoactive effects.
- Some lichens, such as *Radula marginata*, contain cannabinoids similar to those found in *Cannabis sativa.*

Insects, Mammals, and Psychedelics

Humans aren't the only creatures that are affected by and intentionally consume psychoactive compounds. Moths in Arizona favor the intoxicating nectar of *Datura* flowers over all other plants. Spiders weave fantastic webs when artificially subjected to LSD. Flies have long been associated with *Amanita muscaria* in cultures around the world due to the insect's attraction to a compound in the mushroom known as 1,3-diolein. When flies consume the mushroom they become intoxicated, going into a coma-like state for 30 minutes to 50 hours.[17] Many cultures have long thought the comatose flies were dead and thus used the mushroom for insect control. However, the flies eventually reanimate, seemingly unaffected. The fact that insects, like humans, are affected by these compounds means that either: A) this ability was held by the last common ancestor of insects and mammals around 1 billion years ago or B) the ability to be affected by psychedelics is a trait of convergent evolution (that is, it is a successful adaptation), an equally incredible hypothesis.

Some mammals are known to seek out psychoactive mushrooms. Siberian reindeer and Canadian caribou ravenously consume *A. muscaria* and Italian mountain goats are said to become violently defensive of *Psilocybe semilanceata,* which they consume in preference to other foods. Both animals, upon consumption, exhibit notable, and sometimes violent, head twitching.[18] Interestingly, in animal studies the closest animal relative to humans, chimpanzees, are known to self-administer alcohol, heroin, cocaine, caffeine, nicotine, and other addictive substances, but do not seem to prefer psychedelics.[19]

Psychoactive Fungi and the War on Drugs

In 1965, the United States Congress passed the Drug Abuse Control Amendment, which classified psilocin and its related alkaloids as Schedule I substances. Along with heroin and crack cocaine, psiloc(yb)in is considered by the U.S. Drug Enforcement Agency to have a high potential for abuse, no currently accepted medical use in the U.S., and no means for safe use under medical supervision.

All forms of psiloc(yb)in and its relative alkaloids are restricted—whether as pure compounds, in whole mushrooms, or in mycelial fragments. However, in most U.S. states, the spores of psilocin mushrooms are legal to possess and distribute as they do not contain the active alkaloids. I am not aware of any state or federal laws prohibiting the possession or distribution of muscimol.

The criminalization of psiloc(yb)in came just a few years before the official launch of the global War on Drugs, a campaign presumably held by the United States and many participating countries to eradicate the production, distribution, and consumption of a wide variety of natural and synthetic compounds. In the 40 years since its inception, the War on Drugs has failed to achieve its stated goal of eradicating drug abuse and has instead received significant blow back for causing a range of negative effects on various economic, ecological, and social systems. The following are just a few of the many shortcomings of the War on Drugs:

- Statistically, non-white people from a lower socioeconomic background are more likely to be arrested for drug related crimes. Drug related felony convictions often lead to the defendant losing education opportunities, the right to vote, and ease of later employment. When drug offenders leave prison, their lack of social mobility often leads to further illegal activity. The average sentence for a first time, non-violent drug offender is longer than the average sentence for rape, bank robbery, or manslaughter.
- The War on Drugs costs U.S. taxpayers $51 billion annually. An estimated $1 trillion has been spent by U.S. enforcement in the last 40 years.
- The War on Drugs doesn't stop drug addiction. Every year 8–14,000 people die from illegal drugs, and over 500,000 die from legal drugs (liquor, cigarettes, and over the counter and prescription drugs).
- The illegality of drugs supports underground drug markets controlled by organized crime syndicates. The mafia and gangs maintain their control over these markets with violent crimes, thefts, and by the corruption of local police and government agencies. The high cost of black market drugs leads addicts to commit criminal acts solely to support their drug habits.
- Attempts at coca eradication in developing countries have destroyed the heath of this traditionally sacred plant and many other food crops, leaving farmers destitute. At the same time, opium production has skyrocketed in Afghanistan in the wake of the U.S. invasion in 2001.[16]

Many critics have called the War on Drugs a disaster that only serves the perpetuation of U.S. imperialism and military hegemony. As an alternative, some critics have demanded the full legalization of drugs along with the implementation of a more robust accountability structure that effectively addresses the underlying causes of drug addiction. Legalization would reduce the need for a black market and its associated impacts while also reducing the taboo criminalization places on drugs, which, for some, initiates an appeal to their use. As a health issue, the non-violent, personal act of drug addiction should not be seen as a crime, but treated on an individual basis with physical and mental health care that frees the user of their dependency. The crimes that result from drug addiction should be addressed using community-oriented accountability processes, such as *restorative justice*, that require transformation in the offender and assists in supporting the victim. More broadly, the socioeconomic conditions that lead to drug addition (e.g. economic oppression and Western imperialism) would also need to be removed from the structure of any society working to develop a safe, healthy, and just future.

Considering that much of the taboo around discussing psychoactive fungi results from the

Know Your Rights

In the event of a drug-related confrontation with the law, it is important to not offer any information that could later be used to incriminate you. If you are stopped by police, first ask if you are being detained. If you are not being detained, you are technically free to go. The phrase "I am going to remain silent, I want to talk to a lawyer," should be repeated as anything said can—and likely will—be used in court. Verbally refuse consent to searches or seizure of any property; the police must have "reasonable suspicion" to search a vehicle or property. Even if it seems like there is no way out of a conviction, it is best to not say or confess anything to the police until after discussing the case and evidence with a lawyer. These methods of protection apply to U.S. citizens; rights in other countries and for non-citizens may vary. Visit www.flexyourrights.org for more info.

fact that they have been outlawed, the above critiques should be considered in any assessment of these fungi's benefits and limitations. As discussed later, psilocin mushrooms seem to have some medical value, a clear contradiction to their Schedule I classification. To de-stigmatize psychoactive fungi—and, by extension, all fungi—such flawed top-down assessments must be challenged by all who wish to advance human-fungal relations.

Psychoactive Fungi and Culture

Psychoactive mushrooms have played a central role in human life since the development of the earliest civilizations, and perhaps even earlier. Just as the fungal products of beer and bread enabled early civilizations to establish roots and reduce nomadism in pre-history, an abundance of evidence shows that the effects of *Psilocybe* and especially *Amanita* mushrooms significantly impacted the development of culture, philosophy, art, religion, and cosmology in nearly every part of the world where these mushrooms grew.

Altered States of Human Existence

The current timeline on exactly when and how the first forms of human culture developed has not been conclusively established. Anthropologists state that while the evolution from *Homo erectus* to *Homo sapiens* occurred approximately 196,000 years ago,[20] the earliest evidence of humans using symbolic language appeared only 100,000 years ago. Arguably, these early humans had the same intellectual capacity and physical stature that we hold today, yet for unknown reasons it took these distant relatives almost 100 millenia to invent lasting means for expressing thoughts and experiences through art. Today, cultural development is occurring at an exponential rate, with new ideas and creations arising daily. So why did it take humans so long to invent something as relatively simple as symbolic expression?

This question is one of the greatest mysteries of anthropology and is not readily addressed by mere physical limitations or even contextual constraints, such as environmental conditions or the primacy of survival, the types of answers often provided by officials on the topic.[21] While the daily needs of early humans may have slowed their eventual discovery of paint and symbol, it is hard to overlay such simplistic excuses on such a large gap in time. Something dramatic must have shaken the internal landscape of the first artists and shown them a wholly new way of venerating and engaging with the world and perhaps conceptualizing a future where ideas could perpetuate.

Accessing altered states of consciousness could have been this initial catalyst. Considering the great significance that altered states have held and continue to hold in the development and perpetuation of the world's Indigenous cultures, it is not hard to imagine this theory explaining the first leaps into symbolic art. Many cultures today claim that altered states provide them with new information. Much of the art produced in the last 20,000 years has been attributed to altered states of consciousness or spiritual reverence. And yet academia largely refuses to assess the potential that induced trances or the consumption of psychoactive substances influenced the first stages of

human cultural development. Rather, preference is given to more socially acceptable answers that dismiss this great mystery of humanity's history as merely an act of chance.

In his book *Food of the Gods*, author Terrance McKenna attempted to explain one such leap in human development as an outcome of early humans using psychoactive mushrooms. In short, McKenna suggested that around 18,000 years ago early humans accidentally began eating *Psilocybe cubensis* as they foraged for food. Over time, these ancient people realized that in low doses the mushrooms helped increase their "visual acuity," incurring benefits to their foraging practices and ultimately providing an evolutionary advantage to those that consumed the mushrooms. Eventually the mushrooms became central to this early culture and, as the people consumed increasing quantities of mushrooms, their brain size, intellectual capacity, and mating rates increased as a "natural" outgrowth of this practice. Thus, McKenna claimed, eating psychoactive mushrooms helped early humans develop the ability to think abstractly, to form languages, and to artistically express their inner motivations and external experiences on the savannah, all while having a lot of sex. In this "Stoned Ape Theory," mushrooms were a major catalyst in the movement of nomadic tribes out of the savannahs and toward the banks of the Fertile Crescent.

For years after the publication of *Food of the Gods*, McKenna's controversial theory was popularized in psychedelic circles and among mycophiles inspired by the idea of fungi as a potent creator of culture. However, the research of Brian Akers in recent years has helped expose the illogical shortcomings of such a proposal.[22] In sum, Akers points out that the theory is founded on many unsubstantiated claims that have to be accepted in whole. Each claim is nearly impossible to validate on their own, yet McKenna asks the reader to accept them all, lest the entire theory falls apart. Such demands make for a rather questionable approach to substantiating an evolutionary theory. Further, Akers points out that McKenna's primary claim that psychoactive mushrooms "increase visual acuity" is a complete misrepresentation of the data it was supposed to be based upon. The paper McKenna cited to support his claim was not even based on tests of visual acuity but, rather, other parameters of vision, as noted in the quote to the side.

There is a "natural" tendency to misjudge the position of the visual as compared to the gravitational vertical. A 160 µg/kg psilocybin-induced accentuation of this misjudgment... is reported. Psilocybin...consistently increases the natural misjudgment of the [Apparent Vertical Visual]... At its worst, such disorientation may be compared to a "jammed computer" state, a condition which ***may not be conducive to the survival of the organism.*** *[Emphasis added]*

—Fisher & Hill (1963)[23]

McKenna's other main argument that mushrooms make you horny, thus you breed more, thus your culture trumps all others, is also not reflective of the various evolutionary pressures that are the true influences in the success of a species (e.g. strength, size, diet, and immunity). Lastly, as Akers points out, the idea that mushrooms can cause evolution on their own makes little sense as fungi do not (to our knowledge) mutate genes and thus cannot cause true evolution in the genetic sense of the word.

Though McKenna's theory held several major errors, such clarifications do not dismiss the importance that altered states have had on countless human cultures. Altering one's perception of reality has seemingly been a central feature of human existence throughout history, as suggested by the world's oldest cave art located near Chauvet, Lascaux, Pech Merle, and Altamira, France. Dating from roughly 30–40,000 years ago, these enormous works depict scenes of hunting and handprints, as well as strange *therianthropes*: half man-half animal creatures reminiscent of the shapeshifting attributes of shamans from more recent times. While most anthropologists ignore the implications of these paintings (or *psychograms*), it has been strongly argued that they were inspired by altered states of consciousness.[24]

However, these cave works may not have necessarily been the byproduct of their creators consuming psychoactive substances. In his book *The Origin of Consciousness and the Breakdown of the Bicameral Mind*, psychologist Julian Jaynes suggests that humans only began to use psychedelic drugs approximately 3,000 years ago in response to the loss of a more natural ability to access modes of thinking that would be considered uncommon today. In Jaynes' theory, the majority of human history and civilization was guided not by people forming decisions with the surface level of conscious thinking that is so heavily promoted today but, rather, by ancient people following the guidance of "voices" that came from their subconscious. That is, humans were deeply in touch with their subconscious (what we may think of as intuition today) and fully embraced the wisdom it offered. In the bicameral mind, humans were deeply connected to this wisdom and worked with, trusted in, and valued that inner oracle's help in the development of life ways that were holistically tuned to the environment. But as human civilization progressed, the bicameral connection was eventually lost and drug use arose as an attempt to maintain a pact with this silenced guardian of

human life. In essence, drugs became a surrogate for a once-central aspect of the human psyche and hallucination came to replace infallible intuition as the latter was quickly forgotten in the grave of humanity's naturalistic heritage.[25]

Whether endogenously or exogenously induced, altered states have long served as a vehicle for transferring otherwise inaccessible knowledge of medicines, cosmology, spirits, and perhaps even genetic functioning.[26] It is only in the last few thousand years that this incorporeal counsel has become increasingly undervalued due to the violent traumas inflicted on the spirit of mankind. The Nature-based spiritual practices of traditional cultures have been systematically destroyed in the genocides of Indigenous societies by conquering nations. And in their place, a globalized, mass-produced culture has become increasingly offered as the primary route toward finding one's purpose. Simultaneously, the once-common values and lifestyles of traditional cultures are spoken of abstractly, in romantic terms, or, conversely, with the assumption that such ways are outdated or impractical. As this disconnect deepens, a growing desire amongst those in various counter cultures to return to the ways of the past is understandable, perhaps even unavoidable.

But to fully respect the offerings of Nature-based spiritual practices, modern researchers into such traditions must acknowledge the full range of customs that defined the belief systems of each culture. Though many traditional cultures have and continue to use altered states and psychoactive substances, they often incorporated additional practices that assisted in the hard work of purging negative habits, confronting and healing personal traumas, and manifesting social change, so as to embody the insights of the altered state. All of these practices were interwoven and inseparable.

The Varieties of "Shamanic" Experiences

A wide variety of traditional practices have been developed by cultures around the world for inducing altered states. Done correctly, rhythmic drumming, fasting, sweating, dancing, spinning one's body, sleep or light deprivation, or the consumption of certain plants or fungi have all been used historically to bring about a variety of altered experiences of reality. In these states, the practitioner may seek to divine information, praise or appease deities, alter weather patterns, balance etheric energies, communicate with the deceased, communicate with plants and other non-human organisms, clarify one's life purpose, or reinforce spiritual beliefs. Depending on the tradition, whole villages may have engaged in these practices together and one or several practices may have been used. Often the whole event was guided by a specific person or small group: the medicine person or people of the community.

Despite this range of activity, historians and others interested in these customs often place these complex practices together by describing them all as forms of "shamanism." Not only is this blanket term vague, it is also technically inaccurate as the word itself derives from a single custom and location. The word "shaman" is derived from the *Amanita*-using Evenki (formally Tungus) people of northern Siberia. For the Evenki, *šamán* means "diviner," "magician," "doctor," "creator of ecstasy," and "the mediator between the human world and supernatural world."[27] Dutch travellers only brought this word to the West in the late 17th century. With few similarities amongst these various cultural practices apart from the medicine person ("shaman") entering a trance state to leave their body and/or communicate with spirits or ancestors, the term "Nature-based spirituality" can be used as a more descriptive term that does not simplify many geographically and culturally distinct groups of people through language.

As awareness of psychedelics has grown in the last century, the variety of Nature-based spiritual practices has also achieved greater coverage. Increased anthropological research has helped document these customs, while authors in the counter culture have worked to popularize the beliefs and practices of many cultures. Though many of these works document these cultures holistically, others tend to place an emphasis on a given culture's use of psychoactive plants and fungi to the exclusion of various other cultural dynamics. Such selective descriptions are unfortunate for they not only risk skewing dialogues around how cultures have practiced Nature-based spirituality, but these writings can also suppress the fact that many traditional cultures have never consumed psychoactive substances as a part of their customs.

In The Book of Highs, *author Edward Rosenfeld lists over 250 ways to alter consciousness without drugs.*

Such ethnographies often ignore the fact that some traditions have used their shamanic practices for reasons many in the West would consider negative. These aspects of "dark shamanism" include the use of plant and animal poisons, energetic warfare, sorcery, and even cannibalism.[28] While such practices are common in certain cultures, they are often ignored in the literature due to their tendency to detract from the more positive (or drug-friendly) aspects of these foreign cultures.

Selective interpretations of Nature-based spiritual customs are not only incomplete, they may also support subtle forms of prejudice against the Indigenous people being described. By only acknowledging the more pleasant, shocking, or "magical" aspects of these practices, an injustice is dealt against these cultures by reducing their complex—and at times violent—traditions to those of "peaceful warriors" and "noble savages." In effect, they become an "other" that can be appreciated and studied safely from afar. Such stereotyping ignores the fact that many cultures and forms of civilization have developed and used weaponry to defend or colonize land, or subjugated the women and/or another facet of their populace to some degree, regardless of whether or not they took psychoactive substances. These cultures can all be viewed in both positive and negative terms, demonstrating that consuming psychoactive substances or mimicking the customs of traditional cultures cannot inherently undermine complex social control systems. In general, healthy cultural transformation can only come about through identifying, addressing, and dissolving the destructive practices and belief systems in a society and in each of its individuals. This does not mean that there is not much to learn from traditional cultures and their customs, just as there is in any study of history. But to be most effective in such efforts, one must identify biases that have been instilled through inaccurate records of the past.

In many cultures, calling oneself a medicine person was not a simple matter of choice. Depending on local custom, shamans might be selected at a very early age and spend their whole lives training for the position. Often, the initiate might go through a number of grueling processes in both the physical and spirit realms to be fully accepted as a healer. This process is often quite traumatic, especially in the astral realm where they may be tortured, torn apart, and reassembled by spirits working to purify the healer.

And yet, people who have never gone through any culturally sanctioned initiatory processes claim the title of "shaman." This is not to say that a person cannot appreciate or adopt the spiritual practice of another culture. But such adoption should only be done by the explicit and direct acceptance, initiation, and training by people of that culture. Without such integration, respect, and support, a self-appointed practitioner would likely be acting as a perpetrator of cultural appropriation.

That said, certain, rare people have also been known to possess natural abilities to access altered states and thereby serve as a conduit for otherwise inaccessible knowledge.[29] It may be that in prehistory such people were honored for their abilities as their unique insights could have helped inform their society's decision making. Prior to the devaluing of these rare individuals that occurs today, these gifts may have been used to creatively, intuitively, and positively guide the growth of culture. Or, as Jaynes suggests, perhaps all humans had these gifts and we have only lost our ability to embrace and safely utilize them in relatively recent years.

Though the romanticism of modern shamanic studies can be problematic, it is often based in an honest desire in the seeker of finding a holistic and healthy way of life. Nature-based traditions can suggest a way to dissolve the illusions of modern civilization and reveal a deeply needed connection to Nature. Most people interested in Nature-based spirituality desire such a way of life that can provide a spiritual rock to sit upon as the chaos of the world spirals out of control.

Thankfully, one may not need to take on the customs of a foreign culture to find ancient answers to life's many challenges. Nearly every modern culture can find roots in an Indigenous tradition, whether in South America, Asia, Europe, or elsewhere. Each tradition hosts its own unique blend of customs, mythology, and spiritual practices that is just as unique and profound as any other. To think that wisdom can only be found in foreign lands is to ignore the potential gifts offered by the traditions and wisdom of one's own ancestors. As so many of the world's traditions are being increasingly eroded in the name of progress, it may be more imperative than ever to ensure that history's variety of cultures do not get lost forever. For some, this may require drawing from deeper aspects of their heritage that were not as destructive or imperialistic as later generations and redefining these legacies in a modern context.

Beringia

If the history of psychoactive fungi should begin anywhere, it should be in the far north of Asia, in the tundra and birch forests of Siberia where the greatest documentation of *Amanita muscaria* consumption is found. The oldest recorded use of this mushroom in Beringia comes from around 1500 BCE, though linguistic research into the Uralic language of the region shows evidence that Indigenous Siberian cultures have known *A. muscaria* to be an intoxicant since approximately 4000 BCE. This mushroom was present in the eastern Asian Siberian-Beringian region during the Tertiair period (ca. 65–2.4 million years ago), and it was from this region that the Fly Agaric spread across Asia, Europe, and North America, with Alaska being the center of diversification of the species' three clades.[30]

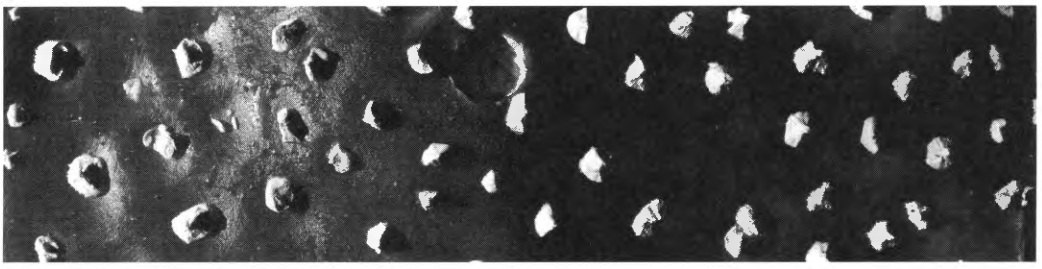
Current cultures of Siberia that work with *A. muscaria* can be divided into two geographical regions: from the Kolyma River to the Kamchatka peninsula (eastern Siberia) where the Chukchi, the Koryak, and Yukagir reside; and western Siberia, where the Khanty, the Nganasan, and Selkup live. While each culture has its own variation on working with the *Amanita,* traditional practices are generally found in one of four contexts:

- Sacred and magic activities (e.g. divination and communicating with the dead).
- The recital of epics.
- During difficult physical work (e.g. haymaking and pulling boats).
- Recreationally as a narcotic, for euphoria, or for dreaming.[32]

The ceremony surrounding the gathering of this mushroom follows a highly structured pattern. The Siberian shaman gathers the red and white *Amanita* under its mycorrhizal pine and birch partners, often placing them on a central tree to dry in the tree boughs by the light of the Sun. When the collection is finished, the shaman fills a sack with the mushrooms and brings them back to the village. There, s/he will travel from yurt to yurt, delivering the mushrooms to community members. If snow levels are high, the shaman may enter through the yurt's alternate entrance in the roof. And if the mushrooms are not fully dried, the villagers may place them in socks or other vessels and hang them over a fire in their yurt.

Many of these Siberian cultures also herd reindeer, an animal known for its rich milk and strong affinity for *A. muscaria.* Reindeer seem to enjoy the intoxicating effects of the Fly Agaric and will often fight each other and their herders over the *Amanita* when it is encountered in the wild. Siberian herders will even place the mushroom on the end of a stick so as to entice reindeer to work. And as the animals will also fight over snow covered in the psychoactive urine from a human or reindeer that ate the mushroom, herders will often carry a canteen of this urine to use as bait for the herd.

In some Siberian tribes, the women roll the *Amanita* into long tubes that the men eat; generally three or more caps are eaten per session. Sometimes the dried caps ("cookies") are rehydrated in reindeer milk.[34] The mushroom can cause nausea in the novice, however, due to the presence of muscarine. So while a tolerance to the mushroom can be built over time, an easier approach to working with *A. muscaria* is to drink the urine of another person or an animal that has consumed the mushroom. As such, the consumption of muscimol-infused urine from a shaman or reindeer is not an uncommon practice in some traditional Siberian cultures. Further, drinking urine in general is not isolated to Siberia. Ancient Hindu texts proclaim many health benefits attributed to "urine therapy," claiming that its minerals, salts, and enzymes are beneficial when taken internally or even applied topically.



The Chuckchi say that the Amanita mushrooms are another tribe and that they accompany those who consume the mushroom on a voyage through their world to visit the land where the dead reside.

"The chita-ko, a specific type of Koryak shaman, will sing and drum as part of traditional divination rites. Each chirta-ko has his own mushroom song, which is understood to be spontaneously bestowed by the mushroom."

—Kevin Feeney[31]

To these cultures, birch trees are held sacred and they say that in the same way that the trees reach to the Pole Star and the heavens, so too by eating the mushroom that grows at their base one may reach the gods beyond.[33]

Let the Agaric remain on earth, and let my children see what it will show them.

—Big-Raven

Santa Claus the Mushroom

Reflecting on the traditional Siberian customs with *A. muscaria*, it is striking to find that it shares many similarities to one of the most famous mythical figures in the world, Santa Claus:

- Santa lives in the far north where he performs many miracles with the help of elves. Santa's understanding is limitless with an omniscience that pierces into the hearts of all people to know who has been bad or good. Like God, Santa is omnipresent as he travels the entire planet in one night being towed by a herd of "flying" reindeer, one of which has a bright red nose.
- Santa is dressed in red and white up top and dirt-colored boots below as he travels the world. He climbs down the chimney of each home to pull gifts out of a magic sack, which he then places in socks over a fire or under a pine tree as red and white presents. Santa eats round cookies and drinks rich milk and, as such, is quite jolly.

These similarities have not gone unnoticed by researchers and one can easily find a surprising number of books and documentaries that present an abundance of evidence supporting the notion that Santa is a mushroom.

Asia and Pacific Islands

Accounts of other Asian cultures using psychoactive fungi are a bit more dispersed. In Japan, *A. muscaria* is called *beni-tengu-také* ("scarlet-goblin fungus") and is associated with trickster spirits known as the *taku*. In China, the divine mushroom, *ling chih* (a name that is commonly associated with red Reishi mushroom) has also been occasionally seen as *A. muscaria*.[35]

In the Philippines, the Igorot aborigines of the island of Luzon consume a drink made from six fresh caps of *Amanita muscaria*, which they call *ampacao*, as a rite of passage.[36] In Papua, New Guinea the Kuma, Mogei, Papus, and Sina-Sina people consume a variety of psychoactive mushrooms which they call *nonda*, *ngam ngam*, *wonda bingi*, or *koobl tourroum*. These mushrooms are said to cause violent rages in the user and/or "Lilliputian hallucinations" in which little people or animals are seen. These species include *Boletus flammeus*, *B. kumaeus*, *B. manicus*, *B. nigerrimus*, *B. nigroviolaceous*, *B. reayi*, *Heimiella anguiformis*, *Russula agglutinata*, *R. kirinea*, *R. maenadum*, *R. nondorbingi*, *R. pseudomaenadum*, and *R. wasgiensis*.[37]

Africa and the Middle East

The best evidence of traditional African work with psychoactive fungi has largely been found in the northern end of the continent. In the Tassili plateau of northern Algeria, the world's oldest representative art of mushrooms is found in 7,000–9,000 year old cave paintings depicting numerous mushroom effigies and anthropomorphized mushroom humanoids. One prominent figure depicts a therianthropic half man-half bee figure with mushrooms projecting from the entirety of his corpus. Artwork in a similar style has also been found in Tadrart Acacus, Libya; Ennedi, Chad; and at Jebel Uweinat, Egypt.

Ancient Egypt is known for its use of psychoactive substances, specifically the blue lotus flower (*Nymphaea caerulea*). However, there is strong evidence that psychoactive fungi were also consumed during this culture's initiatory practices. Ancient Egypt was a matriarchal civilization steeped in the quest for immortality. For over 3,000 years the culture's greatest minds sought to understand the nature of life and death and to uncover the mysteries of reality. Through the mystery schools of ancient Egypt, initiates were taught how to manipulate and control their consciousness, with one goal being the ability to maintain lucidity upon death and to retain one's sense of self after the body passed. Meditation, psychoactive substances, and studies of geometry, astrology, and alchemy were all part of this quest for spiritual growth.

Guzman has proposed the Tassili mushrooms to be Psilocybe mairei.[42]

There is evidence that the ancient Egyptians knew of the effects of *Psilocybe cubensis, Amanita pantherina*, and *A. muscaria*, the latter of which may have been called *eisch-al-ghorâb* ("raven's bread").[38] The work of James Arthur has identified many ancient temples in Egypt that depict mushrooms, many of which look strikingly similar to *Psilocybe* species.[39] In a paper from the *Journal of Ethnopharmacology*, Stephen Berlant argues that various artifacts, headdresses, symbols, and dieties of Egyptian culture were directly related to a reverence for psychoactive mushrooms. While these findings are provocative, they are unlikely to receive much investigation from the universities of the world due to such a proposal contradicting standard interpretations of Egyptology, which tend to exclude psychoactive substances from their analyses. To quote Berlant:

> *"Egyptologists and laymen alike have romanticized the Egyptians and their deities from the very advent of Egyptology. The theory that Egyptian religion and culture was built around the practice of ingesting entheogenic mushrooms, which we now condemn, can create a cognitive dissonance that some people may never be able to resolve."* [40]

This shortcoming reflects the problems in science noted in the Introduction of this book. The most intelligent approach that any person can take toward developing a sound theory of the world and its origins is to look objectively at all of the available data, and from this pool draw conclusions that are based on the evidence. To base opinions on official assumptions is to commit the fallacy of Ad Vericundium (Appeal to Authority), while blindly following popularly held beliefs is the fallacy of Appeal to Popularity. Neither act will uphold science's core principles of objective postulation and investigative validation, but instead further obscure truth behind the gilded veil of a status quo.

Europe South

Every September in ancient Greece, the goddess Persephone's mythic rise from the underworld clutches of Hades and her safe return to her mother Demeter was reenacted in a 10-day ceremony known as the Eleusinian Mysteries. This event was one of the most coveted rituals in Greece and its climax came after a day-long procession from Athens where, on the final night, 1,000–3,000 Athenians gathered in the temple of Eleusis 12 miles west of Athens to have the secrets of the cosmos revealed to them. Here, in the center of the temple, the initiates (*mystai*) congregated in a grand hall (the *telestrion*) where the revelation of the Mystery (the *epopteia*) was performed.[43]

What transpired during the Mystery Night is to this day still largely unknown as participants were sworn to secrecy and little was ever written down about the ritual. It is clear, however, that the revelation revolved in large part around the consumption of a strange, vision-inducing drink known as the *kykeon*, now suggested to have been a brew made from fungi and/or other substances.

One of the more intriguing pieces of evidence to support a fungal-based kykeon theory comes from a Homeric hymn to Demeter dating from the 7th century BCE that lists the ingredients for the kykeon as barley, water, and mint. While these plants are rather inert on their own, the theory of a psychedelic kykeon is based on a plausible extraction of Ergot (*Claviceps paspali*), a psychoactive fungal blight that often grows on barley. Ergot contains d-lysergic acid amide (LSA), a tryptamine psychedelic closely related to the more potent d-lysergic acid diethylamide (LSD).

The problem with this theory however is that Ergot also contains several highly toxic compounds that cause ergotism, a condition in which the extremities of the body lose blood circulation, leading to headaches, psychosis, dry gangrene (similar to leprosy, in which body parts die and fall off), and potentially death. How the Greeks could have prepared Ergot to remove these poisons and still retain the psychoactive properties has (to the best of my knowledge) never been proven, though recipes have been offered.[44] These theoretical recipes are largely based on a claim by the chemist Albert Hoffman that Ergot's psychoactive compounds ergonovine and lysergic acid are water-soluble, while the toxic constituents ergotamine and ergotoxin are not. Therefore, the Greeks *may* have been able to make a safe and psychoactive water extraction of Ergot for the kykeon. These recipes however are purely theoretical. It is not recommended to make any Ergot extractions for consumption due to the risk of death that comes with working with this fungus.

Allego suggests that the root of the Greek word kannabis *is actually based on etymology of words related to* Amanita muscaria. *He also proposes that the Assassins, a gang of Syrian killers from the 12th century, were not high on hashish during battle as is commonly presented, but instead were users of the Fly Agaric. Much like the Viking Berserkers (see below), this mushroom may have been the Assassins' source of rage and bravery.*[41]

The Eleusinian Mysteries were controlled by two elite families, the Eumolpids and the Kerykes, for over 2,000 years. Plato, Sophocles, and many other well-known Greek philosophers participated in the Mysteries. Socrates was killed for performing the Mysteries privately. He had refused initiation because it would have required secrecy and he already knew how to prepare the kykeon.[45] The Mysteries continued until the 4th century CE, when they were ended under Christian law.

Europe North

In the far north of Europe, the Indigenous Sami (formerly Lapps or Laplanders) of modern Norway, Sweden, and Finland have a documented use of *Amanita muscaria* as both a medicine and as a consciousness altering substance. At the beginning of the 19th century, Swedish soldiers were fed dried Fly Agarics to heighten their courage during the Swedish-Norwegian war.[46] Some researchers have suggested that a similar practice was used by the Viking Berserkers (known for their violent and maniacal fighting strategies) to enhance their rage, an interesting but still unsettled and oft-debated argument.

> *"No one who discusses the fly agaric in Europe can ignore the debate that has been carried on for almost two centuries in Scandinavia on this issue. First Samuel Odman in 1784 and then Frederik Christian Schubeler in 1886 propounded the thesis that those Viking warriors known as 'beserks' ate the fly-agaric before they 'went beserk;' in short, that 'beserk-raging' was deliberately caused by the ingestion of our spotted Amanita."* [47]

The colloquial modern Irish term for Liberty Caps is "pookie" or little Pookah. A Pookah is a solitary supernatural creature, a shapeshifter able to cause humans to experience fairy reality in the form of visions, transformations, and hallucinations. The fairy Puck from Shakespeare's play A Midsummer Night's Dream may be a play on this word.[48]

Europe West

Compared to the documented use of psychoactive fungi in northern Europe, evidence for their consumption in the continent's Western region is much more contested. In his book *Shroom*, Andy Lechter argues that, despite the fact that the Liberty Cap mushroom (*Psilocybe semilanceata*) grows abundantly across the British Isles, there is no evidence that the ancient British, Irish, or Scottish people knew of—let alone used—these mushrooms in ritual. However, there is no evidence to suggest that Liberty Caps are not native to Europe, and, as such, it is reasonable to assume that these fungi were just as numerous in the autumns of the distant past as they are today. Indeed, it is difficult to imagine that the powerful effects of this mushroom were not discussed among, if not utilized by, the highly spiritual Indigenous cultures of the area, such as the Celtic and Druidic people.

Soma is the link between the space of wild(er)ness which is also the space of "original intimacy," and the space of cultivation and separation. It is also the space of "light and victory," and of the "rest at the high point of Order." Around the Soma-function revolves a dialectic of reconciliation of the wild and the tame, and of all the other dichotomies so dear to the Structuralists—male/female, raw/cooked, and so on. Soma is a type of the tertium quid, twoness as oneness.
—Peter Wilson[50]

In his book *Ploughing the Clouds: The Search for the Irish Soma*, Peter Lamborn Wilson (a.k.a. Hakim Bey) presents a range of striking examples from Celtic art and mythology that suggest the ancient people of Ireland did indeed use psychoactive mushrooms. In Lamborn's analysis, the mythologies of these people, so often dismissed as fairy tales, were metaphors of initiatory or shamanic practices interwoven with cryptic references to the use of mushrooms as portals to the magical land of these elves, fairies, and their kin.

Across the United Kingdom are found megalithic dolmens: massive stone buildings of unknown age or origin. Some, such as the Chûn Quoit in Cornwall, bear a strong resemblance to a mushroom. Celtic traditions claim that these structures serve as entrances to the fairy world.[49] However, archeologists often refer to these small structures merely as tombs, though no strong evidence exists to substantiate this claim. Others have suggested that these buildings could have just as easily served as small temples or meditation spaces by ancient peoples, just as caves have been used in other parts of the world as sites of contemplation and initiation. Erupting like mushrooms from the fields and rolling hillsides of the British Isles, these dolmens do resemble aboveground caves, womb-like by their cavity and yet phallic in their form. Other dolmens (some more mushroom-shaped than others) are found in Korea, India, Russia, Spain, Italy, Turkey, Algeria, and many other countries where their traditional purposes are often unknown. And, as noted in Chapter 3, it can be conjectured that, considering the context of her burial, the ancient Red Lady of Spain may have consumed *A. muscaria* as an act of the ancient elite.

Rätsch states that Spanish women accused of being witches in the Middle Ages used Psilocybe semilanceata *as a visionary inebriant.[51] Ergot may have been used in French occult divination practices.[52]*

North America

In North America, the documented evidence of Native American and First Nations Peoples using psychoactive fungi as a sacrament is scarce. This may be due to a lack of documentation, the refusal of nations to share their practices with outsiders, or for the actual lack of traditional practice with these fungi. A singular account of a 400-year history of *Amanita muscaria* use amongst the Ojibwe people was presented in 1978 by the Anishinaabe researcher Keewaydinoquay.[53] However,

Keewaydinoquay's account has been contested due to the fact that it is not supported by any other detailed ethnographies of traditional Anishinaabe cultural practices.[54] Further, the story that Keewaydinoquay presents of *Amanita* use is itself not strongly supportive of a truly "shamanic" tradition. Rather, she describes the mushroom as a means for intoxicating women so that they could be taken advantage of sexually.[55]

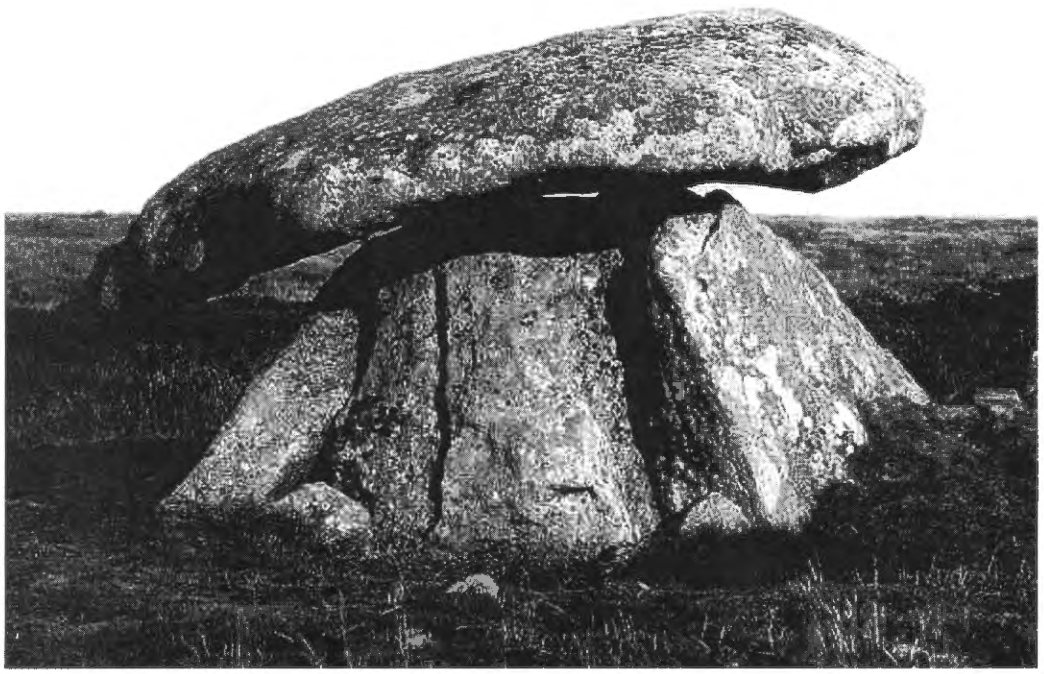
The Ojibwe are one of the largest Native American nations and the second largest First Nation of Canada; they are located predominately around Lake Michigan and Lake Superior on both sides of the U.S./Canada border.

Despite the fact that muscimol- and psilocin-containing fungi grow abundantly throughout the northwestern U.S. and southwestern Canada, accounts of traditional, ritual-based use of these fungi by the Coast Salish, Chinook, Quileute, or any of the many other Indigenous people of this region are absent from the literature. The same can be said of the southwestern nations (such as the Hopi) where, despite the presence of endemic psychoactive mushroom species, there is no documented evidence of traditional use amongst the local Indigenous cultures in recent centuries. Some petroglyphs found in the southwest region have been interpreted to suggest ancient mushroom use, but supporting evidence of this hypothesis is lacking.[56]

Central America

Compared with the U.S. and Canada, Central America has a much richer—or at least better documented—history with psychoactive fungi. It seems that one of the earliest Mesoamerican civilizations, the Olmecs, worked with psychoactive mushrooms, a practice that has been linked to aspects of Olmec were-Jaguar,[57] underworld decapitation, and Venusian resurrection mythology and iconography.[58] *Amanita muscaria* was likely the preferred species used in ancient Mesoamerica until *Psilocybe spp.* and other psychoactive plants took preference.[59]

The Mayan culture (ca. 2600 BCE–900 CE) followed in the footsteps of the Olmecs as artifacts from this era show evidence of psychoactive fungi being used in ritual. In the first half of the 20th century, the work of archaeologist Stephan de Borhegyi helped develop the theory that reverence for psychoactive mushrooms was central to Mesoamerican cultures. Borhegyi identified some 300 carved stones in modern day Guatemala, Mexico, and El Salvador that feature human and animal figures with predominant mushroom-shaped caps above their heads. These mushroom stones have been dated to the time of the Pre-Classic, Classic, and Post-Classic periods of the Mayan empire (ca. 1000–500 BCE); many were discovered alongside *metates*, grinding stones presumed to have been used for preparing the mushrooms.



Chûn Quoit in Cornwall, UK. This ancient megalithic dolmen has an unknown origin and purpose.

Borhegyi's son, Carl de Borhegyi, has pursued his father's legacy to further substantiate claims of a mushroom legacy among the Maya and Olmec. Borhegyi bases his work on a wide array of artifacts that seem to centralize psychoactive mushrooms in each culture's mythology and cosmology as well as their associated obsession with the underworld, death, and resurrection. He suggests that the mushrooms were given to society members (perhaps in the form of an enema) who were to be ritually sacrificed.[61] Even players of the famous Mayan ball game may have been under the influence of psychoactive mushrooms. The ball game is thought to have symbolically represented aspects of the sun, fertility, duality, and stories of the underworld of Xibalba. The game was an integral aspect of Mayan culture and major games were celebrated as important rituals, with the winner being decapitated as a sacrifice to the gods.

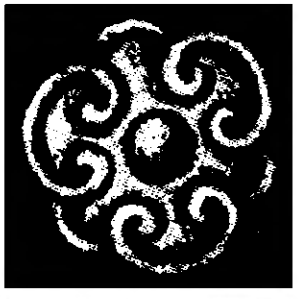
The clearest written accounts of traditional Mesoamerican practices with psychoactive fungi come from the codices and Spanish records of the Aztec empire (ca. 1300–1600 CE). During the conquest of Latin America, Spanish priests travelled to the west to chronicle the destruction and discoveries of the conquistadors. In a 16th century document known as the *Florentine Codex*, the Franciscan Friar Bernardino de Sahagún wrote extensive accounts of Aztec mushroom use. To quote the Codex directly:

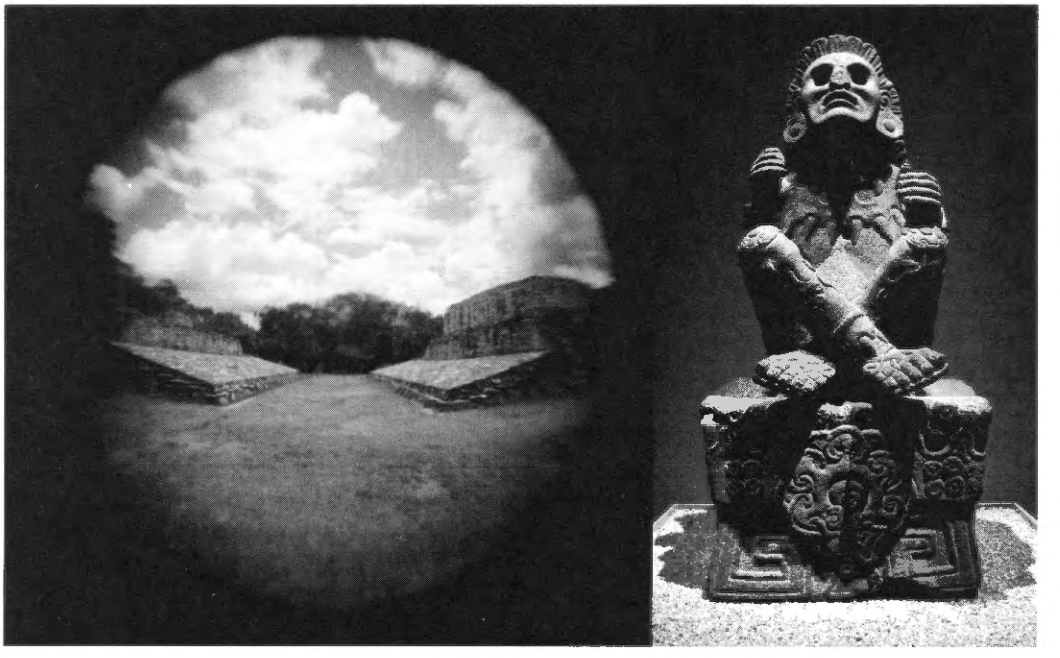
> *"At the very first, mushrooms had been served. They ate them at a time when, they said, the shell trumpets were blown. They ate no more food; they only drank chocolate during the night. And they ate the mushrooms with honey. When the mushrooms took effect on them, then they danced, then they wept. But some while still in command of their senses entered and sat there by the house on their seats; they danced no more, but only sat there nodding."*

The mushroom stones have also been suggested to simply represent culinary mushrooms or that they were used as tools for shaping pottery.[60]

The Aztecs called the mushrooms *Teonanácatl*, or *Teunamacatlh*, a Nahuatl[63] term that translates as "wonderous mushroom" or "God's flesh." Users of the mushroom were transported to *Tlalocan*, a paradise ruled over by the rain god Tlaloc, where they experienced a "flowery dream." It is thought that Teonanácatl was used to generically describe multiple psychoactive mushroom species of the region. Evidence of mushroom use is also found in the art of the Mixtec *Codex Vindobonensis*, the Aztec *Magliabechiano Codex*, and in the Tepantitla frescoes of the great city of Teotihuacan. In the *Vienna Codex*, the god Quetzalcoatl is clearly shown being tutored in the use of mushrooms.[64] Psychoactive fungi were also used at the coronation ceremony of Moctezuma II (the last ruler of the Aztecs) in 1502.[65] Upon coronation, human captives were sacrificed in Moctezuma's honor and the King ate a stew made from their flesh.

Sacred mushrooms such as the Amanita muscaria *and psilocybin were likely consumed before the ritual ballgame. The effect would have been to greatly enhance the player's perception of strength and bravery and give him an illusion of invincibility.*
—Carl de Borhegyi[62]





(Left) A Mayan ball game court.

(Right) Xochipilli, the prince of flowers.

(Above) Carved into the knees of Xochipilli was this emblem, later interpreted to be Psilocybe aztecorum.

In the mid-19th century, a 16th century Aztec statue was unearthed on the side of the volcano Popocatépetl near Tlalmanalco, Mexico. The statue was of a human figure resting on a pedestal in a state of what was later deemed drug-induced ecstasy. Named Xochipilli ("prince of flowers" in Nahuatl) after the Aztec god of art, games, beauty, dance, flowers, and song, the figure was adorned with emblems that have been interpreted to represent various psychoactive plants and fungi of the region: mushrooms (*Psilocybe aztecorum* or others), tobacco (*Nicotiana tabacum*), *Ololiúqui* (Morning Glory, *Turbina corymbosa*), *sinicuichi* (*Heimia salicifolia*), possibly *cacahuaxochitl* (*Quararibea funebris*), and one unidentified flower.[66]

Quetzalcoatl is often represented in close association with Tlaloc, the god of rain, fertility, and thunder.

It is interesting to note that although the Aztec culture built on the legacy of the Maya and seem to have been much heavier consumers of psychoactive fungi than the Maya, the Aztecs appear to have been an incredibly violent culture. Compared to the Maya, the Aztec elite sacrificed humans in large numbers to appease the gods Tlaloc and Quetzalcoatl. Further, the Aztec empire was largely a warring monarchy that spent much of its resources on expansion and the conquest of smaller nations. The Mayan city-states, on the other hand, were relatively autonomous. Mayan states were led by priests, and much of their time was spent studying the stars and developing highly advanced measurements of time.

South America

Despite the fact that many psychoactive fungal species grow in South America, possible evidence of traditional mushroom use in this part of the world is limited to gold artifacts from Pre-Hispanic Colombia. Known as the Darien pectorals, these artifacts seem to depict mushrooms.[67] Yurimagua Indians in Peru have been reported to eat a tree mushroom (potentially *Psilocybe yungensis*) to get "drunk."[68] Carl de Borhegyi, following on his research into the Olmec and Mayan cultures, suggests evidence of mushroom use among the ancient Nazca, Inca, Chavin, Chimu, Mochica, Paracas, and Easter Island cultures.[69] No contemporary aboriginal groups of South America are known to regularly consume psychoactive fungi.

Psychoactive Fungi in Symbolism and Myth

A startling number of common connections have been made by various world cultures between certain symbolic motifs and psychoactive fungi, especially *Amanita muscaria*. Akin to the connections made between fungi and rebirth in Chapter 3, this mushroom has repeatedly been connected to death, resurrection, and various mythical lands and creatures. Some of the more alluring points include the following:

- The mushroom experience of a spiritual death and rebirth may have been foundational to the Mayan and Aztec human sacrificial practices. The choice of beheading as the method of killing may have been in reference to the consumption of the mushroom cap, where the majority of the active constituents are found. After these sacrifices, psychoactive mushrooms were often eaten by the whole society. Similarly, attempts to raise the dead in the Anthesteria rituals of Dionysian cults may have been a reference to the consumption of psychoactive fungi.
- Venus is the Morning and Evening Star in the sky, heralding the rebirth of the Sun each morning and trumpeting the solar death beneath the horizon each night. In the Mayan culture, Venus was seen as the God of Life and Death and intimately connected to mushroom-fueled sacrificial rituals that sought immortality. John Allegro suggests Venus was seen by early fertility cults to both embody the regenerative/feminine principle while also being a celestial phallus glans from which procreative semen (in the form of dew) spread across the land each morning, inseminating the Earth to give rise to the *Amanita* as a heavenly incarnation.[70]
- The Yggdrasil tree, or world axis, was a central feature of Norse cosmology. Yggdrasil directly translates to "Odin's Horse."[71] In Norse mythology, Odin's horse was said to fly across the sky, dropping a mixture of spit and blood that, once landed,

gave rise to *Amanita muscaria* mushrooms. In the Big-Raven story of the Siberian Koryak people, the spit of the deity Existence gives rise to an *Amanita muscaria* that Big-Raven eats. The Siberians held the birch tree sacred, perhaps in part for its mycorrhizal relationship to *A. muscaria.*

- As scavenger birds, ravens have often been associated with death and, by extension, served as a symbol for the knowledge that comes from death and a subsequent (spiritual) rebirth. In Nordic lore, two ravens (Húgin ["Thought"] and Mumin ["Memory"]) accompany the god Odin and provide him with knowledge of battles.[72] The first grade of initiation in the cult of Mithras was called Raven or *Corax.*[73] The bird is also known to eat the Fly Agaric. In Koryak mythology, Big-Raven was told to eat the *Amanita* (*wapaq*) by the deity Existence (Yahiynin) so that Raven would have the strength to lift a great whale. *A. muscaria* was called "Raven's Bread" in Afghanistan, Siberia, and Egypt.[74]
- The pinecone has been used in many cultures as a symbol for spiritual illumination. In Babylonian carvings, gods are shown holding pinecones. The staffs of the pope, Dionysus, and Osiris all have pinecones incorporated into their design. In the center of the Vatican courtyard is a giant statue of a pinecone. Some have suggested the pinecone refers to the pineal (pine-al) gland in the brain, which has a similar shape and may be the site of endogenous DMT production. *A. muscaria* has also been associated with the symbol of the pinecone due to its mycorrhizal relationship at the base of pine trees.
- Mushrooms have been connected to the mythical realm of the Greeks known as Hyperborea,[75] a perfect land "beyond the North Winds." Similarly, *A. musciaria* has been symbolically linked to the Empyrean: the highest heaven of Greek mythology that was linked to the element of Fire.
- Mushrooms have been symbolically connected by researchers to mythical creatures and folk tales of numerous eastern and Western cultures. The half lion/half eagle griffin,[76] the serpent,[77] gnomes, fairies, shade foots,[78] werewolves, bears, Medusa, and even Atlas with the world on his shoulders have all been considered symbols of psychoactive fungi.[79]
- As the shapers and stewards of their environments, mushrooms and bees have long been associated with each other in various cultures, as noted in Chapter 3. Eleusinian initiates ate honey to symbolize their new life from illumination.[80] The processing of psychoactive mushrooms into meads is a popular practice among consumers of these mushrooms today.
- The single eye has long been used as a symbol of intelligence and spiritual illumination. Ruck suggests the glowing eye and numerous other symbols used in Freemasonry, a secret society steeped in ancient esoteric magic and ritual, are direct references to psychoactive fungi and the "illumination" that comes from their consumption.[81] Odin was also known as Har and Bileyg, both meaning "one-eyed."
- Ruck argues that the stories of Snow White and Hansel and Gretel are direct references to the *Amanita.* Irvin suggests that the tale of Little Red Riding Hood symbolically masks an initiatory process involving the *Amanita.*[82]

Mushrooms and Religion

In the 1940s and 50s, a group of documents dating from the 3rd century BCE were discovered in the Kumran region of Palestine's West Bank. Written in the ancient language of Aramaic, the Dead Sea Scrolls (as the texts came to be known) were deemed to be authored by the Essenes, an early sect of Jewish mystics. The discovery of the Scrolls was significant as their age made them the second oldest existing documents associated with the Old Testament of the Bible and their interpretation held unequivocal insights into the theology and practices of this important pre-Christian sect.

When the scrolls were first uncovered, few scholars in the world could accurately translate

their text; and of the few that could, most were directly related to, or working for, the Christian church establishment. However, among the small team of translators who were granted access to the scrolls was John Allegro, a cultural historian, theologian, and philologist from the UK. Allegro was the only translator not affiliated with the church and, as a philologist, was on the team to offer both a literal translation of the scroll's text as well as deeper insights into the meaning of the words the Essenes used, as defined by their evolution from older languages. Allegro could explain how a word to an Essene did not necessarily hold the same connotation that it would to a 20th century British person due to the vastly different relationships each culture held with their use of language.

Philology: *The branch of knowledge that deals with the structure, historical development, and relationships of language or languages.*

As translations began, it soon became apparent to Allegro that disparities were arising between the Essene theology he was interpreting and the translations of his peers. While the other members on the team gave relatively mild reports that were essentially in line with existing church doctrine, Allegro's unbiased transcriptions reflected a very different message and one that the church establishment ultimately refused to accept.

In 1970, Allegro's book *The Sacred Mushroom and the Cross* was published documenting decades of research into the philological interpretations of early Judeo-Christian texts. The revelatory book presented substantial evidence that the religious practices of the Essenes were directly influenced by use of psychoactive fungi, many of which laid the foundations for later religions. A brief summary of this thesis is as follows:

> *To the earliest forms of human society, fertility of land, animals, and mates was of the greatest importance. From a primal necessity to ensure the continuation of life, early humans developed complex rituals to venerate the concept of fertility and to appease what they saw as various gods associated with its control. Among the many practices of these early people, sex rites and the idolatry of phallic and vulvic symbolism were commonly used to increase abundance and reproductive potential in the land. The rituals evolved in various ways to eventually incorporate a variety of symbols, objects, organisms, and natural phenomena that embodied attributes of the fertility principle and thus wielded power over this central aspect of life. Among these ritualized objects, the* Amanita muscaria *mushroom was one of the most idolized. With its unique blend of vulvic and phallic characteristics, coupled with the mushroom's production of god-like sensations in the consumer, this miraculous hermaphroditic gift of the forest floor was seen as a complete embodiment of the fertility principle and as a highly venerated deity in the cult's pantheon.*
>
> *These early fertility cults and their rituals ultimately laid the foundation for later forms of religious practice, such as the indulgent cults of Mithras and Dionysus and, eventually, to early forms of Judeo-Christianity.*[86] *However, as these major religions grew, connections to their roots in sex- and mushroom-based fertility cults were destroyed. Some knowledge of this occulted history did survive in the form of cryptically encoded myths and fables, all interwoven with reference to the teller's mycological ancestry. Some mushroom symbolism survived in various forms of art and elaborate dress, while overt references to the past were suppressed. Allegro points to red and gold Jewish turbans as one example of this encryption.*[87] *Similarly, the red Phrygian, mushroom-like cap of Mythraic cults can still be found on the seal of the United States senate, the flag of Paraguay, and as the hat of Santa Claus.*

"That distant otherworldly Garden of the God [Hyperborea] was supposedly peopled by Gorgons and creatures with a single eye, the Arimaspeans; its plants, guarded there by griffins, were called golden fruits or flowers of gold and subterranean honey. All of these—the one-eyed tribesmen, the Gorgons, the griffins, and the other monsters, the golden fruit and the so-called honey—are metaphoric for the Siberian entheogen, Amanita muscaria*..."*[83]

Referring to the Anthesteria, Allegro writes "...to eat the god [mushroom] was to die with him; in the short hours of the initiate's complete communion with the deity he had 'died' to the world. It was then that he was at most fearful risk, and the days of careful preparation for the ultimate mystery were given their most crucial testing. This was the time of 'trial' or 'temptation' through which every participant in the cult passed."[84]

Considering the controversy such a revision of religious history provokes, Allegro's peers soon deemed his work to be heresy despite the fact that his scholarship were never found to be at fault (apart from a few minor mistakes involving transposed letters and numbers). Ultimately, Allegro's career was ruined, yet to his death he stood behind his interpretations and his evidence that ancient fertility cults lay at the heart of Western religion. Many still dismiss Allegro outright due to the controversy that surrounds his work. However, many of his contemporary critics fail to recognize that the claims originally launched against Allegro were unfounded.

Sumerian Names for A. muscaria

**LI-KUR-BA(LA)G-ANTA/AN-TI- TAB-BA-R/LI-TI*
**LI-MASh-BALAG-ANTA KUR-KUR*
**MASh-TAB-BA-R/LI-TI*
UKUSh-LI-LI-GI
**TAB-BA-RI-GI*[89]

In his 2009 book *The Holy Mushroom*, researcher Jan Irvin demonstrates that many of the original claims laid against Allegro's work were launched by Gordon Wasson without substantiation.[88] Unlike Allegro, Wasson was not a professional historian or a philologist. Rather, Wasson was primarily a public relations agent known for his books on psychoactive fungi. Due to his status as a

The ubiquity of the mushroom cults cannot be explained by physical contact between different cultures. It is most easily seen as the result of shamanic communion with the plant itself, reinforced by notions common to humanity, what Jung called the archetypes and Plato termed the rememberances and re-cognitions—anamnesis—from the empyrean.

—Jonathan Ott[85]

The dove is often used to represent Jesus in art. Often shown with wings spread, the bird's silhouette shares a strong resemblance to that of the Amanita cut in half. The dove is considered the counterpart of the raven.[90]

In the phallic mushroom, the "man-child" born of the "virgin" womb, we have the reality behind the Christ... also of the initiates of the cult, "Christians," or "smeared with semen," as the name means. By imitating the mushroom, as well as by eating it and sucking its juice, or "blood," the Christian was taking unto himself the panopoly of his god... In the language of the mystery cults that sought to be "born again," when, purged afresh of past sin, they could apprehend the god in a drug-induced ecstasy.

—John Allegro[91]

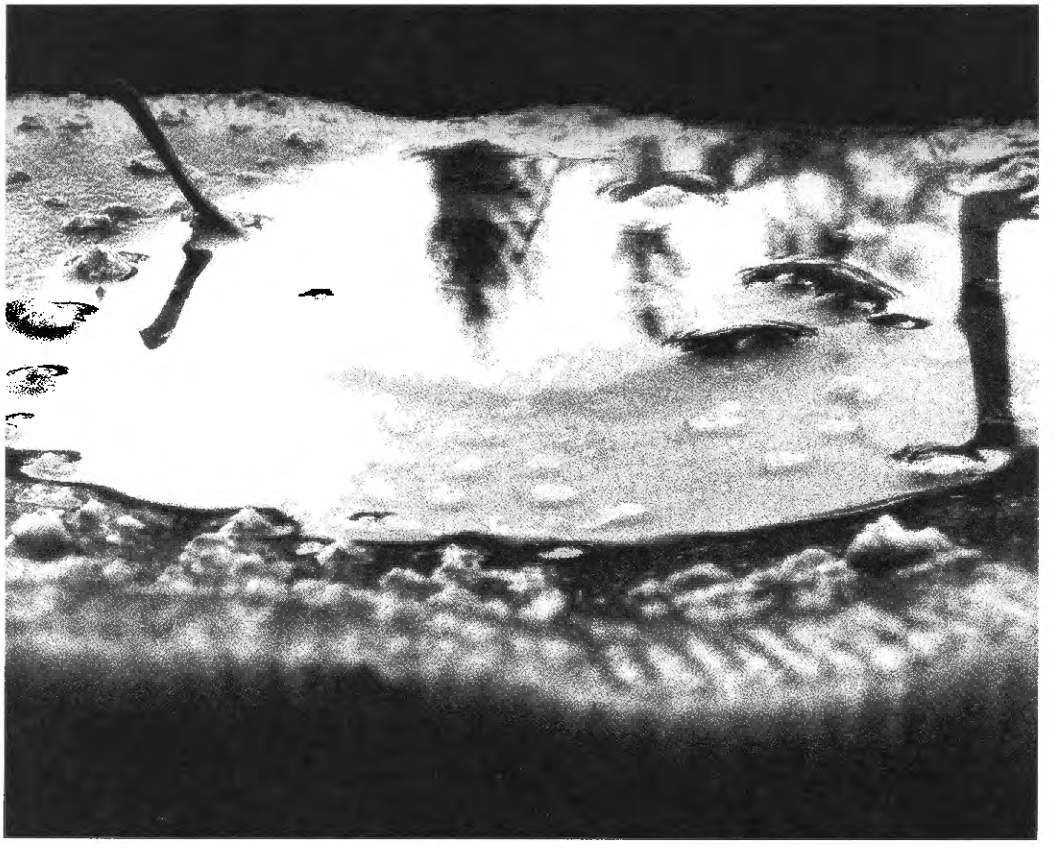
Not only could the drug contained under the skin of the sacred fungus give to the initiate at will this illusion of spiritual resurrection, of victory over death, but in the conception and growth of the mushroom he could see the microcosm of the whole natural order. Before his eyes the cycle of life and death was enacted in a matter of hours. The Amanita muscaria *was the medium of spiritual regeneration and at the same time in itself the supreme example of the recreative process in the world of Nature. No wonder the fungus attracted so much awesome wonder among the ancients, or that it inspired some of literature's greatest epics.*

—John Allegro[92]

mycological celebrity, Wasson was able to discredit Allegro, despite the fact that Wasson even admitted to never reading Allegro's work. Today, many critics of Allegro still use Wasson's unfounded claims to silence discussion on ancient mushroom worship.

Still, a number of researchers have followed up on Allegro's research in recent years to gather a wealth of evidence supporting the theory that psychoactive mushrooms did influence the development of major world religions. As an ancient language expert, Allegro focused on the root meanings of words. These other researchers have looked into Christian artwork and the strange and confusing symbolism of the Bible's text. Literature on this subject is quite robust, with various authors offering well-researched theses that critically analyze both the New and Old Testaments. Of these works, two points commonly recur:

- **The Tree of Knowledge of Good and Evil was a mushroom:** The forbidden fruit in the Garden of Eden, which brought Adam and Eve knowledge of the true nature of reality and is often depicted as a red and white apple, was a symbol for the red-outside, white-inside *Amanita muscaria* that "fruits" beneath trees. In the creation story, Eve is created from the rib of Adam, just as the red phallic mushroom erects prior to the veil pulling away from the "rib" of the mushroom stalk to produce the singular "breast" of the cap.
- **Jesus was a mushroom:** Just as the mushroom arises from no apparent seed, so is the Christ figure born of a virgin into this world to perform miracles as God incarnate. The silhouette of the crucified savior, with his crown of thorns and sash, shares a strong resemblance to the *Amanita* with its single leg, outstretched cap, crown of warts, and skirt. At the last supper, the disciples are told to eat the flesh and drink the blood of Jesus. The Holy Grail, said to have held the blood of the savior, is reflected in the upturned cap of the Fly Agaric, which is known to hold red-tinged, psychoactive rainwater.



Hinduism

In 1968, Gordon Wasson published the book *Soma: Divine Mushroom of Immortality* in which he argued that the venerated intoxicant *soma* of the Hindu Rig Veda texts was made from *Amanita muscaria*. Of the 1,000 holy hymns in the Rig Veda, more than 100 are dedicated to Soma. Two major components of Wasson's theory came from descriptions of soma as *Aja Ekapad*, "the Not-Born Single-Foot," a term which appeared seven times in the Rig Veda,[94] and from clear allusions to urine drinking in some of the hymns.[95]

Since *Soma's* publication, numerous researchers have followed up on Wasson's claims to support or discredit its thesis. Some critics suggest that soma might have referred to a class of drugs, like the use of the terms "dope," "psychedelic," or "hallucinogen" today. Irvin argues that soma is a generic term describing single or combined preparations of *Amanita*, *Psilocybe*, Syrian rue, *Nyphaea*, *Nelumbo*, *Cannabis*, opium, *Ephedra*, and/or other psychoactive ingredients.[96]

Many other Hindu myths, sculptures, and artifacts have been interpreted as referring to psychoactive fungi. In the Pine Forest story, Shiva and Parvati are locked in an endless sexual embrace, where Shiva's phallus, called the White Vajra ("white lightning bolt"), is coupled with Parvati's vulva, called the Red Lotus. This reflects the growth of the mushroom where the tearing of the partial veil reflects the hymen breaking by the shaft of the erecting mushroom. This symbolic form of hermaphroditism is also seen in depictions of Shiva alone as half-man, half-woman.[97]

[M]ushroom worship, by its own extreme nature, its fanaticism and bouts of uncontrolled frenzy, bred its own opposition among normal people. More balanced religionists condemned these aspects of the cult, and the Old Testament records successive attempts by kings and prophets to purge its "abominations" from the land. But they were too deeply rooted to be wholly successful. Even the most intensive and successful purges...simply drove the mushroom cult underground, whence it re-emerged in later centuries far more dangerously in the politically oriented movements, Zealotism and Christianity.

—John Allegro[93]

Buddhism

Scholarly research into work with psychoactive fungi in ancient Buddhist practice is scarce. One paper from the Journal of Ethnopharmacology claims that symbolism surrounding an alchemical elixir used by 2nd and 9th century Buddhist *siddhas* to attain "realization" can readily be interpreted as references to *Amanita muscaria*.[98] In his online book *Secret Drugs of Buddhism*, Mike Crowley draws from 40 years of Buddhist practice and research to propose that the mysterious *amrita* potion often referenced in Vajrayāna Buddhism was historically related to the soma of Hinduism, perhaps as *Amanita muscaria* or *Psilocybe cubensis*. While today practitioners of this early form of Buddhism drink a non-psychoactive form of *amrita*, Crowley suggests that the mushrooms were used historically to help practitioners induce the state of *śunyatā*, "non-duality" or "nothingness."[99] Buddha became enlightened while sitting under the Bodhi tree, a potentially metaphoric reference to the Tree of Life or Tree of Knowledge. This tree is often mushroom-shaped in many sculptures of the Buddha. Legend states that the Buddha died and entered Nirvana at the age of 80 after eating a mushroom.

Other names for soma in the Rig Veda include Deathless, Honey, Navel, Pillar, Bull, Red Bull, and Fire (Agni).

I am huge, huge! Flying to the clouds. Have I not drunk soma?

—Rigveda X: 119

Alchemy

Alchemical texts used highly symbolic artwork and writings to convey their philosophy and occult knowledge to those initiated in the Art. Yet as many of the original documents of Alchemy are lost to us today, contemporary researchers must speculate as to what many of these symbols and terms were originally referring.

Much of alchemical iconography embodied the philosophic principles of Hermeticism, especially in regard to the power found through a unification of opposites, or "chemical wedding." It was said that through the combination of opposing forces, the work of the alchemist could transcend physical dualism and manifest unified consciousness in both the material they were working with as well as in their own psyche and spirit. The dragon, hermaphrodite (rebis), Sun and Moon, along with the colors red, white, and black were all symbols frequently used to convey this principle of collapsed dualism. While most alchemical researchers consider these symbols as embodiments of an idea, in the book *Magic Mushrooms in Religion and Alchemy*, professor Clark Heinrich suggests that these symbols referred to an actual being that embodied this principle: *Amanita muscaria*.

For Heinrich, the hermaphrodite of the alchemical world is the *Amanita*, where its red-tipped, phallic form, single testes (base), penetrated vulva (cap), white shaft (stalk), torn hymen (partial veil), and breast (cap) covered in "white drops of semen" (universal veil remnants) all served to ex-

There are many bird analogues for the arcane substance...but none so perfectly matched to the life cycle of the mushrooms as is the phoenix. It is the red firebird, hatched from an egg, which spends all its life in its nest. It feeds its young with drops of blood, meaning that young mushrooms will be round and the color of blood. It lifts its fiery wings and "consumes itself" in flames, leaving nothing but "ashes" in the nest...Some versions of the myth say the bird becomes a worm after it burns, an allusion to the worm infestation that is likely to occur by the time the mushroom's "wings" are fully uplifted; when they finish their work in an unharvested specimen only worms and "ash" remain in the nest. From its own ashes the firebird will then be reborn, whether phoenix or fly agaric.

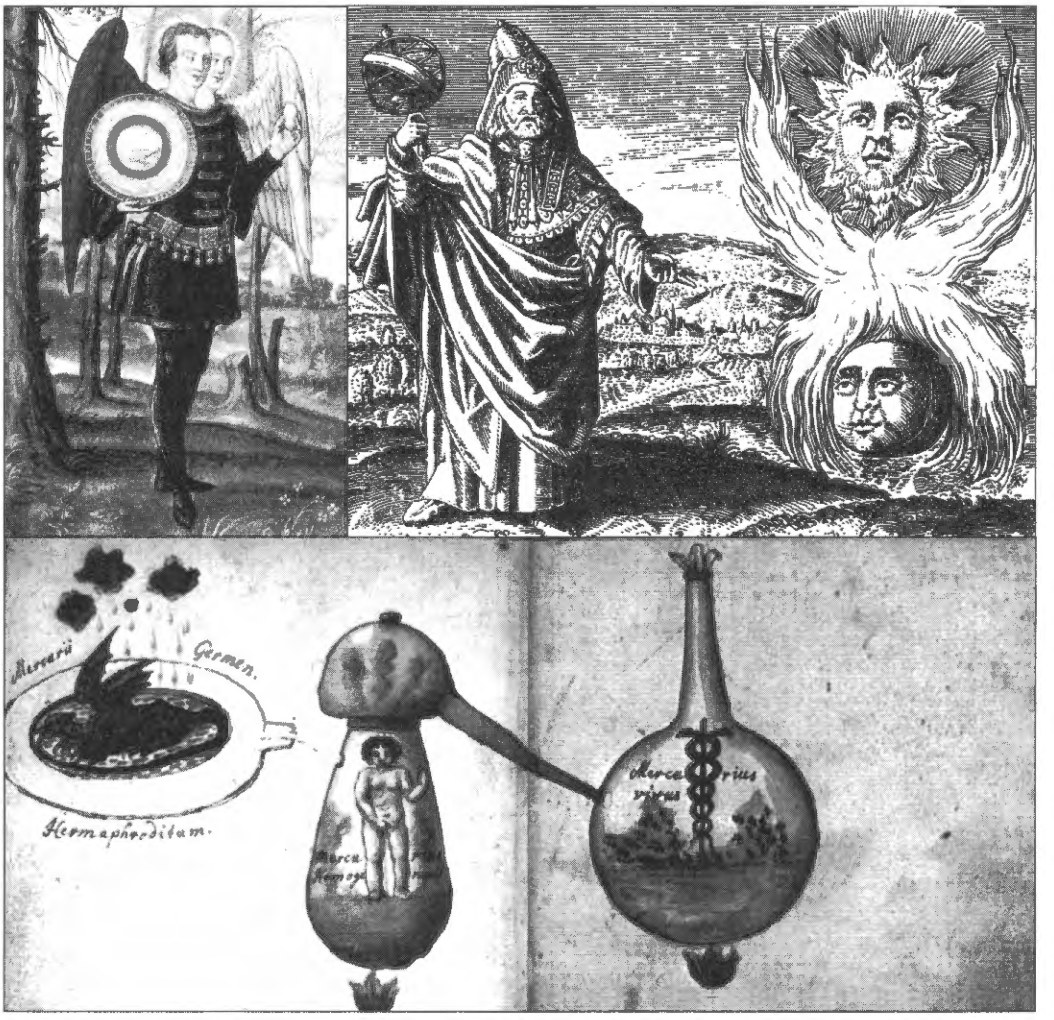
—Clark Heinrich[100]

The tribal rug is a patch of civility in the wild, the city rug a patch of vice versa... In like manner, the Soma-function manifests within each major era of technological ordering, within each "seizure of History," as vegetal yin to crystalline yang, as the secret wilderness embedded within the topocosm of the sacrifice. Ibn Khaldun's sociology of the wild and the tame serves as a dialectics for the analysis of these power flows, for a politique of Soma. In this sense the garden is the emblem of Soma, the site of an alchemical complementation of plant and crystal, the mythogem of paradise, symbolized in certain prayer carpets.

—Peter Wilson[101]

emplify the chemical wedding in a single living organism. The white vulva and red cap reflected the companionship of Sun and Moon, while the mushroom's life cycle reflected the eternal rebirthing of the mythic phoenix. Alchemists used the dragon, Ouroboros, and winged serpent to symbolize the combination of heavenly and earthly aspects, just as the mushroom is both of the Earth but also divine by its power of expansion. In alchemical artwork, a small human (the homunculus) was often depicted in beakers urinating a mysterious liquid gold (the *aqua permanens* or *aqua divina*) as part of lab processes, a potential reference to the urine consumption required for the full *Amanita* experience.

Despite the incredible depth of experimentation that ancient alchemists took to explore products of the plant, mineral, and animal realms, existing early alchemical literature lacks any reference to works with *any* fungi. Considering this gaping hole in recorded research, I must wonder if ancient alchemists intentionally suppressed their knowledge of mushroom preparations to draw attention of the uninitiated away from the most powerful species in the fungal realm. Could it be that a lab-based alchemical preparation of the divinely radiant *Amanita muscaria* was one of the philosopher's stones? Was this quintessential mushroom the final key to unlocking the knowledge of life and death, of reception and projection? It seems quite possible to me that the answer was, "Yes."



Alchemical images potentially alluding to the use and preparation of Amanita muscaria.

(Left) The red and white hermaphrodite, with a pendant skirt and glowing disk, holds a white egg while standing nearly one-legged under a pine tree.

(Right) Hermes Trismegistus with the Sun and Moon combined in a shape that is similar in appearance to a young Amanita, which is also red above and white below.

(Bottom) The homunculus urinates inside a mushroom-shaped alembic near a winged serpent.

Philosophy and Psychoactive Mycology

By Peter Sjöstedt-H

Due to the general legal prohibition and modern cultural taboo against fungi that contain psychoactive chemicals, the academic discipline of Philosophy has left a potentially bounteous field of enquiry into the nature of reality virtually unharvested. The aim of this text is to introduce the idea of how ingestion of such psychedelic mushrooms can open the doors to an unimaginable universe of cognition, a universe that can highlight and augment Philosophy itself: magic mycology is fuel for Philosophy.

Found prolifically throughout the Western world and beyond, the Liberty Cap mushroom (*Psilocybe semilanceata*) is one of the most potent and common of the psychoactive fungi. An intake of over forty or so dried Liberty Caps (approximately two grams) can bring one into what seems to be another realm. Although the effects vary from person to person, certain features remain somewhat constant in this state of *psilocybin consciousness,* or *"psi-cons."* One experiences feelings that are novel, and therefore ineffable—without words existing to which they could refer. One travels through what seem to be galaxies, one meets apparitions, insectoid beings, spriggans, spacecrafts that try to communicate, etc. *ad infinitum*. "Normal" emotions can increase in intensity; perceptions, concepts and feelings can become intertwined and thereby lose distinctness as such. Time can seem to oscillate in rate, and space loses meaning as one enters a most fascinating mode of experience, which after five (normal) hours or so departs.

One obvious field to which study of the experience of psi-cons applies is the Philosophy of Mind. Neuroscience can be included within this field, but the area mostly involves itself with broader questions that relate to how the mind can be understood within a wider worldview. Philosophy of Mind might incorporate metaphysics, language, evolution, and other disciplines that provide the groundwork and anchor-points for explanations, rather than the purely mechanistic foundation of most neuroscience. One sub-category of Philosophy of Mind is "phenomenology," the study of reality from the initial standpoint of consciousness, or what Immanuel Kant (1724–1804) called "phenomena." This is in contradistinction to studying the world as if the objects we perceive exist precisely as they are perceived by us humans with our particular biased ways of perception. Phenomenology concerns itself then with the study of the multitude of conscious states known to mankind; psi-cons provides an intense, vast annexation to that knowledge. That the study of phenomenology as it exists today has virtually excluded any study of psi-cons is akin to zoology excluding any study of mammals.

Until recently Logical Behaviorism dominated the Philosophy of Mind. This is the view that consciousness does not exist, but that language deceives us into believing that it does. In fact, it contends, all mental terms—such as "happy," "angry," "curious," "belief," etc.—merely refer to physical behavior, not to mental forms. One of the rationales for this Behaviorism was the fact that states of consciousness cannot be empirically verified, only their physical correlates can. I cannot empirically perceive your happiness, but I can perceive your smile. This is ultimately based on an epistemology (theory of knowledge) that asserts that anything that cannot be empirically verified cannot be known to be true, excepting mathematics and logic. This limiting epistemology has a long history but came to prominence at the start of the 20th century under the name Logical Positivism. After undergoing psi-cons, one realizes the absurdity of Behaviorism: whilst practically motionless, without any behaviour, a "psychonaut" will undergo a rapid increase in consciousness rather than the decrease that Behaviorism would suggest.

More generally, materialistic explanations of the mind seem to become less feasible after psi-cons. Perhaps the body is not moving, but surely the brain is highly active, somehow *causing*, or *being*, these psi-con experiences? In philosophy and biology there exists the so-called "Hard Problem of Consciousness." This is the problem that no matter how well one understands the processes of the brain and the nervous system as a whole, one still will not thereby understand how physical movements cause, interact, or are identical to, conscious states, or "qualia." Dopamine activity may be correlated to the qualia of satisfaction, but a material physiological study will only show one

that physiological activity is occurring—it will not show one the process whereby that activity is translated into the feeling. Since the work of the French philosopher René Descartes (1596–1650), Western thought has focussed explanations on the reduction of everything to matter and mechanism. With consciousness, that reductionist mode of explanation reaches its limit. As the great British philosopher Bertrand Russell (1872–1970) put it, "there will remain a certain sphere which will be outside physics...it is obvious that a man who can see knows things which a blind man cannot know; but a blind man can know the whole of physics."[102]

Fundamentally, any explanation of consciousness is founded upon one's epistemology: one's theory of knowledge. One's epistemology is closely linked to one's sense of identity, and thus epistemic disagreements often become heated as they circumnavigate the personal. Psi-cons allows one to escape from the epistemology inculcated throughout one's life. The marvels of Nature become wondrous once more because they do not automatically get swept into pre-formed epistemic categories of thought, such as "leaf," "building," "painting," and so on. A "leaf" can offer an awe-inspiring delight of vision, with its nexus of veins, its reservoir of green tones indicating its sublime photosynthetic machinations.

One notion within our contemporary paradigm of belief is that consciousness is necessarily conditioned by a brain: no brain, no mind. However, under psi-cons this idea seems less tenable. The French Nobel laureate philosopher, Henri Bergson (1859–1941), made the argument that the brain filters consciousness to one's bodily requirements, but that the brain does not create consciousness. This would imply that decreased brain activity could actually mean increased, raw, unfiltered consciousness. Recently, such an inverse correlation has been observed.[103] Bergson drew the analogy between a radio and the program it was playing, with a brain and the consciousness linked thereto—damage the radio or brain, and one can have correlated programmatic or mental damage. However, this does not logically imply that the radio produces the program or that the brain produces the fundamental essence of consciousness. Bergson's contention that memory, the essence of consciousness, was not dependent on a brain has recently been corroborated by, for instance, the discovery that slime molds have a memory despite, of course, not having a brain.[104]

The argument here is that psilocin acts by inhibiting brain activity, thereby increasing mental activity, generally speaking. The implication is that consciousness, or at least a basic form of subjectivity, is an aspect of all organisms. This concept is known as panpsychism, or panexperientialism. The great mathematician and philosopher A. N. Whitehead (1861–1947) argued that all of existence was actually living, there being no difference in kind (but only degree) between what is commonly distinguished as the organic and inorganic. His "philosophy of organism," or Process Philosophy, can be summarized in his assertion that "biology is the study of the larger organisms; whereas physics is a study of the smaller organisms."[105] This does not mean that tables or cables have their own subjectivity, but that the partly self-organizing entities that compose them do, from organism, to cell, to molecule, to atom and beyond. Such a philosophy, linked to hylozoism (the philosophic notion that all is alive), may very well seem preposterous to a person with an epistemic base rooted in post-Cartesian thought. This is essentially because it transgresses the axioms that uphold that thought. But as Friedrich Nietzsche (1844–1900) stated, "rational thought is interpretation according to a scheme we cannot escape."[106] We think that mind is conditioned by brain, but this has never been proven. Strictly speaking, we cannot even prove that other people have minds, known in Philosophy simply as "The Problem of Other Minds." Technically, to assume that the mind is caused by the brain due to psycho-physical correlation is to commit the fallacy *cum hoc ergo propter hoc* (i.e. correlation does not imply causation). Psi-cons opens one to novel lanes of thought seemingly incredible in a contemporary normal state of mind—thinking not only outside the box, but questioning the box's very existence, or becoming it.

Panpsychism and its ilk does not of necessity imply Dualism (i.e. that mind and body are two separate substances). The neo-Kantian philosopher Arthur Schopenhauer (1788–1860) argued that the world was composed of subjective "wills," or drives, that were merely represented by us humans as spatio-temporal matter. Thus, matter as such is caused by our human form of subjectivity, rather than human subjectivity being caused by matter (as brain). Matter and mind, in this form of what is known as Transcendental Idealism, are both aspects of a single reality (Monism), rather than the

interaction of two substances (Dualism), as is common to many religions.

Schopenhauer was a follower, with important qualifications, of the aforementioned great Prussian philosopher Kant. Kant is known for instigating the "Copernican Revolution in Philosophy."[107] He argued in a most rational way that we do not perceive objects as they actually exist, rather objects exist in the way they do because we humans automatically "translate" a given world into forms conforming to our mind's structures. Thus, reality is divided into phenomena and noumena: how things *appear* and how things actually *are*, respectively. For Kant, even space and time were not real but were projected by us onto the real, the noumenal. In this sense, perceived "everyday reality" is the hallucination. As Albert Einstein (1879–1955) wrote, "I did not grow up in the Kantian tradition, but came to understand the truly valuable which is to be found in his doctrine...only quite late. It is contained in the sentence: 'the real is not given to us, but put to us (by way of a riddle).'"[108]

One frequently reported occurrence in psi-cons is the strange contraction and dilation of the speed of time—a minute can seem an hour; an hour, a minute. Space also distorts in unexpected flows. Both effects conduce the idea that psi-cons is interfering with the normal functional mode of mental projection, perhaps allowing the person to gain a glimpse of noumena, the "real reality" not encaged by absolute space, time, or other categories of mental projection. Kant believed that humans could not access noumena, but perhaps psi-cons are a key.

Schopenhauer drew out the consequences of the view that space and time are not real, namely that reality cannot have spatial or temporal distinctions: no past or future, no here and there. Fundamentally all is one—the study of which is called henology. This view has a tradition going back to at least the ancient Greeks, and especially to the neo-Platonist thinker Plotinus (204–270 CE). Schopenhauer applies this metaphysical insight to his ethical theory. For him, compassion was the intuition of this underlying henology, and this was thus the basis of his ethical theory, thereby linking the two philosophical fields of metaphysics and ethics.

Psi-cons certainly can suggest this ethical approach that deifies compassion, an emotion that can be pushed to intense levels in this state. However, such pleasantries should not be overstated with regard to psi-cons. There exists also what can be called the dark psychedelic state: visions of horrific, Bosch-like spectral demons and vast alien expanses, to express but a fraction. To a certain extent, these dark visions and concomitant feelings are a part of what is called the "sublime."

A couple of centuries ago there was much discussion regarding the "beautiful and the sublime," triggered by William Smith's 1739 translation of an ancient Greek book on the subject by Longinus (1st or 3rd century CE). Under psi-cons, one's aesthetic sense is greatly intensified. Objects usually shunned suddenly are appreciated for their astonishing beauty, be this natural or artificial (even that distinction often breaking down in the state). The sublime was described by Edmund Burke (1729–1797) as a feeling of delightful awe caused by some possible terror. In psi-cons, this sublime can reveal itself through inhuman terror—though this can be feared or relished, depending in part upon one's character and indoctrination.

If one has been brought up in a typical Western religious setting, such sublimity might be met with an adverse reaction. Indeed Edmund Burke, in his book on the topic,[109] quotes Milton's portrayal of Satan (see sidebar) as an exceptional example of the sublime. In psi-cons one can at least ostensibly become the figures one sees—the sense of self also disintegrates in this state, opening up further questions about identity.

A number of thinkers have suggested that the psychedelic state is identical to the mystical state. This suggestion alone makes psi-cons invaluable to the Philosophy of Religion. When one reads the mystics' accounts, their experiences often seem indistinguishable from that of psi-cons. Whilst a mystic's religion may influence the interpretation of the experience, the substratum is recurrently of the same kind. A luminescent figure can be interpreted as an angel, a deva, an alien, a ghost, a fairy, and the like, but the figure remains as such. There are many theories regarding the origin of the various world religions; the intake of psychedelics must be considered a worthy contender, as proposed by Aldous Huxley[110] (1894–1963), amongst others.

We aptly end our exploration of philosophy and mycology with Political Philosophy, and consider the assertion of the "Father of Classical Liberalism," John Locke (1632–1704): "the end of law is not to abolish or restrain, but to preserve and enlarge freedom."[111] That a fungus shown to pose

Thir dread commander: He above the rest
In shape and gesture proudly eminent
Stood like a tower; his form had yet not lost
All her original brightness, nor appeared
Less than the archangel ruin'd, and th' excess
Of glory obscured: as when the sun new ris'n
Looks through the horizontal misty air
Shorn of his beams; or from behind the moon
In dim eclipse disastrous twilight sheds
On half the nations; and with fear of change
Perplexes monarchs.
—Milton, Paradise Lost, book 1

no danger to health (in fact, one that is conversely shown to have therapeutic properties, as well as having great academic import), and that such a fungus that commonly grows in local pastures is prohibited by threat of severe punishment by many nations—even listed as a Schedule I drug by the United Nations—is an affront to human dignity and an affront to reason itself. It is a restraint on the freedom of thought, possibly on religion, and indubitably a restraint on cognitive liberty. Psychoactive mushrooms no doubt ought be revered rather than feared, respected in the former manner. We must alter the current impression of them, and allow psychedelic consciousness to once more enter the academic field of philosophic enquiry.

Psychedelics in the 20th Century

Despite the range of traditions that ancient humans developed to work with psychoactive fungi, their incorporation into human cultures was largely suppressed or forgotten between the 17th and 19th centuries. Around the turn of the 20th century, the concept of psychedelic substances was restricted to peyote, *Cannabis*, and opium. It wasn't until a series of reports in the first half of the century were released that fungal-based psychoactive compounds reappeared in Western cultures.

Albert Hofmann, Ergot, and LSD

In the early part of the 20th century, Albert Hofmann, a chemist at Sandoz Laboratories in Switzerland, was researching extracts from the fungus Ergot (*Claviceps purpurea*) for their potential to help induce uterine contractions in pregnant women and to control excessive bleeding during childbirth. In 1938, while synthesizing and modifying the various Ergot compounds, Hofmann produced a modified form of LSA (the psychoactive compound theorized to be involved in the Eleusinian Mysteries of ancient Greece) that was 100 times more psychoactive than its parent alkaloid. This substance was the powerful tryptamine d-lysergic acid diethylamide (LSD), or "Delysid" as Hofmann originally called it.

R. Gordon Wasson and "Magic Mushrooms"

Around the same time that Hofmann was experimenting with Ergot in Switzerland, an Austrian ethnobotanist working in Mexico, Blas Pablo Reko, heard rumors of ceremonial mushroom use by Indigenous Mexicans outside of Oaxaca. Following the tip, Reko went to the south of Mexico where he not only confirmed the report but also collected specimens of these mushrooms from fellow Austrian ethnobotanist Robert J. Weitlander, and subsequently shipped them to Richard Shultes, a mycologist at Harvard University, for identification. Though the mushrooms deteriorated in transit, Shultes was able to identify the mushrooms to the genus *Paneoleus*. Seeking more accurate identifications, in 1938 Reko and Shultes travelled to the village of Huatla de Jimenez outside of Oaxaca, where they collected three species of psychoactive fungi used by locals: *Panaeolus sphinctrinus*, *Stropharia* (*Psilocybe*) *cubensis*, and *Psilocybe caerulescens*. Shultes reported his findings in the journal *American Anthropologist* in 1940.

In 1952, author Robert Graves sent Shultes' article to an associate and mushroom enthusiast R. Gordon Wasson, encouraging Wasson to follow up on the story.[113] In 1953, Wasson took the first of several trips to Huatla de Jimenez in search of local medicine people (*curanderos*) working with these fungi. Wasson returned to Huatla in 1954 and again in 1955 when, on June 29th, Wasson and photographer Allan Richardson attended a ritual (or *velada)* with the curandera Maria Sabina in which they consumed the mushrooms. Wasson travelled regularly to Mexico until 1962, during which time he assisted the French mycologist Roger Heim in documenting nearly 20 new species of psychoactive fungi in the region.[114]

Wasson and Life Magazine

In the May 13, 1957 issue of *Life Magazine*, Wasson published a photo essay documenting his velada with Sabina as well as other Mazatec mushroom practices. Entitled "Seeking the Magic Mushroom," the article not only introduced the now-familiar epithet for psychoactive fungi, it was also the first mainstream piece of writing to reintroduce the concept of using psychoactive fungi since their widespread suppression centuries prior. The article even included field guides to the mushrooms themselves. Six days later, the magazine *This Week* published an interview with Valentina Wasson, Gordon's wife, entitled "I Ate the Sacred Mushroom," bringing the *veladas* story to over 12 million more readers, many of them housewives.

With coverage in such heavily circulated publications, the mushroom practices of Mexico were rapidly launched into the public sphere and into the burgeoning post-modern beatnik counter culture. In the following years, hoards of proto-hippies soon descended upon the hillsides of rural Oaxaca in search of the magic mushroom. But, lacking any roots in the local culture, many of these *gringos* would flash money to any villager (*curandera/o* or not) who could offer them a mushroom trip. Later, these outsiders would be found lying in the village streets, intoxicated and babbling.

Eventually, techniques for home cultivation of these fungi were determined and travel to Mexico decreased in the counter culture. However, the negative impacts that the Wasson articles had on Oaxacan villages can still be seen today. Maria Sabina has since become a tourist icon in the region where her face is plastered in various shops in the state of Oaxaca and illicit mushroom sale and consumption is a major aspect of the area's underground tourist industry.

As there is no documented use of Spanish conquistadors consuming mushrooms with the Aztecs, Wasson and Richardson seem to be the first documented foreigners to partake in consuming Mexican psychoactive fungi. However, they were not the first Westerners to eat psychoactive mushrooms of another culture. In 1790, Polish soldier Joseph Kopec ate Amanita muscaria *for medical purposes.*[115]

Psilocin Mushrooms in Mexican Cultures

The Mazatec people living in the hills outside Oaxaca may count the largest number of mushroom-using healers among their ranks, but many other Indigenous Mexican cultures also work with psychoactive fungi. These include the Chinantec, Chatina, Mixe, Zapotec, and Mixtec of Oaxaca; the Nahua and possibly the Otomi of Puebla; and the Tarascan of Michoacan.[116]

The ceremony surrounding mushroom use by these cultures takes a variety of forms. For Maria Sabina, the mushrooms were always administered in pairs to represent the duality of the feminine and masculine aspects of Nature.[117] Sabina often took 26 mushrooms while patients would take 12 each. Sabina worked exclusively with *Psilocybe cubensis, P. Mexicana,* and *P. caerulescens*[118] and she sang songs throughout the ceremony. These songs were often difficult to translate, however, as she spoke what she called *nahualtocaitl*, the idiom of the divinity.[119] Other curanderos required that sex be avoided for one to eight days prior to the ritual and that there was no eating eight hours prior. The day following the mushroom ceremony, orange leaf infusion was drunk and chocolate eaten but no other food was consumed until midday.[120]

Hofmann Synthesizes Psilocybin

After Wasson's *Life Magazine* article was published, Roger Heim contacted Albert Hofmann to see if Hofmann would be able to identify the active compounds in the Mexican mushrooms. Hofmann agreed, and when samples of *Psilocybe mexicana* arrived in his lab, two of Hofmann's colleagues, Arthur Brack and Hans Kobel, determined the means for growing the mushroom's sclerotia. It was from these sclerotia that, in 1958, Hoffman first isolated and described the psychoactive compounds psilocin and psilocybin.[122] Hofmann later synthesized an analogue of psilocybin, which he called Indocybin or CY-39.

For years, Sandoz Labs sold Indocybin for research and clinical use in psychedelic psychotherapy. With his associations, Gordon Wasson later became the director of the New Jersey subsidiary of Sandoz.[123] *Shulgin gives a recipe for the synthesis of psilocybin in* TIKHAL.[124]

Psychedelic Psychotherapy

As news about the effects of LSD and psilocybin reached the medical community, physicians began investigating the potential clinical applications of these novel compounds. Psychologists were especially intrigued by the drugs' ability to remove mental barriers in the user, making them more susceptible to regression work and suggestions from the therapist. As psychedelics had yet to garner

any social stigma, they were used throughout the 1950s in both clinical practice and recreationally by many members of the scientific community. This experimental field of psychedelic psychotherapy showed the compounds to have some clinical applications, especially in regard to helping treat serious addictions and other self-destructive behaviors. At times, positive results were obtained within just a few sessions. By 1962, psychologists working with LSD were able to obtain abstinence rates of 50–90% in their alcoholic patients, often with minimal negative effects. In a meta-analysis by Dr. Nicholas Malleson, 20 years of psychedelic therapy showed that of 4,303 patients and over 50,000 psychedelic-assisted studies (mostly involving LSD), the most negative reactions to the research were two suicides and 37 patients demonstrating psychotic reactions that lasted over 48 hours.[125]

LSD's effectiveness was thought to be due to its ability, under certain conditions, to reduce the patient's fear of facing the past while at the same time making the past more accessible and objectively observable. While many clinicians saw potential in these compounds to address psychological disorders, research in the field abruptly ended in the 1970s when LSD and psilocybin became controlled substances in North America.

Psychedelic "Spirituality"

As research into the psychological benefits of LSD continued in hospitals around the world, a small group of clinicians sought to uncover similarities between the cognitive effects of psychedelics and "standard" descriptions of spiritual experiences found in various world religions. In one study in particular—the now-famous Good Friday Experiment of 1962—Harvard psychiatrist Walter Pahnke and psychologist Timothy Leary administered 30-milligram doses of Sandoz's synthetic psilocybin to a group of 10 Boston University theology students in the small basement chapel of their school's Marsh Chapel while a Friday mass was being held on the main floor above them. The goal of the study was to determine whether the drug would induce a "mystical experience" in the experimental group. As a control, a second group of 10 students were given niacin tablets.

Soon, it became apparent who had consumed this placebo and who was under the influence of the psychedelic. As the study progressed, the group under the effects of psilocybin became increasingly enraptured by the sermon of the preacher, which they could hear bellowing from the speakers in the floor above them, as intense hallucinations of divine communion were conjured by the overwhelming religious symbols of the chapel's pews, pulpit, altar, and stained glass windows.

After the experiment ended, the participants each completed a survey about their experience. Along with a 6-month follow up study, the results of this questionnaire were used by researchers to *quantitatively* conclude that the experimental group's experience was *qualitatively* identical to "mystical" moments described by world religions. This study was long used by psychedelics advocates to substantiate claims that psychedelics are inherently "spiritual," and that the term "entheogen" (which translates to "producing the god within") was the most appropriate title for these drugs.

This experiment has been criticized on several points in the years since, with much emphasis being placed on the problems with the follow-up study. Remarkably, flaws in the experiment's foundational premises and design are rarely discussed. That is, the experiment was held in an environment that was not neutral, but overlaid with rich spiritual symbolism. Not only were spiritually inclined theology students used, the psychedelics were administered on a holy day and in a holy place where loud gospel and reverential singing were audible above the experimental group.

Another surprising aspect of the experiment's design is that Timothy Leary, who oversaw the experiment, was well aware of the fact that the physical location and mental preparation of a psychedelics user (the "set and setting" of a psychedelic experience) can significantly influence the drug's subjective effects. Adding to these design flaws was the fact that Leary insisted that the people who lead each of the two groups were to be on 15 milligrams of psilocybin themselves, though the experiences of these leaders and their psychological influence on the experimental group were never recorded in the final report.

With such a design, it is not surprising that the experimental group had such an emotionally charged experience. If these people had consumed the same amount of psilocybin in a morgue, strip mall, or nursing home it is quite likely that their subjective experience would not have been

nearly as "spiritual." It could have even been quite frightful in such environments. Ultimately, the Good Friday Experiment provided a false positive in regard to a supposedly inherent spiritual aspect of synthetic psilocybin.

Psychedelic Shortcomings in a Time of Uprising

As psychoactive mushrooms and LSD became increasingly popular in the counter culture movements of the 1960s and 70s, rising celebrities in the psychedelic scene began evangelizing visions of a "turned on" world. Among these authors and speakers, the above-mentioned Timothy Leary stands out as one of the most notorious proponents of psychedelic use. Throughout this era, Leary travelled the world with famous artists to preach the gospel of psychedelics, finding support in writers like Jack Kerouac, Ram Dass, Neal Cassady, Allen Ginsberg, William Burroughs, and Ken Kesey, who all used their celebrity to promote these powerful compounds as a direct means for revolutionary cultural change. Leary's most famous pro-drug slogan of "turn on, tune in, drop out" was repeated like a mantra by millions of predominately white young people who sought to live in a world where the war machine had been decommissioned. Seeking alternatives, the ears of many fell on Leary's call to leave tradition at the doorway to an altered state ascension filled with a counter culture of hippies and freaks.

This popularization of psychedelics coincided with the growth of the 1960s and 70s social and environmental movements where, for the first time in history, civil rights, imperialism, war, gender equality, and freedom of consciousness convened in global dialogues on cultural reformation. As a node in this web of upheavals, the psychedelic state became intimately connected to the people's struggles and was often used to reinforce the era's increasingly stark awareness that a world out of balance demanded new ways of thinking and being. In these rising calls for change, many followed the romantic suggestions of Leary and others who stated all psychedelic journeys would help pave an untraveled road toward salvation.

As the years progressed, the once-connected social movements of the mid-20th century became increasingly splintered. Covert government programs such as COINTELPRO infiltrated many grassroots organizations to cause internal divisions while the various movements crafted their own, and ever more complex, dividing lines. Many in the pro-drug scene focused so heavily on psychedelics that liberation of one's mind came to eclipse the freedom and safety of one's body, people, or planet.

Five decades later, the rhetoric of the early psychedelic era can now be viewed in hindsight with Leary's approach to cultural change representing many of the shortsighted values and tactics offered to the dissatisfied youth of the world. The laissez faire "drop out" approach to revolution was, in essence, nothing more than a vague hope that free love and lots of drugs are the missing keys to unleashing mass cultural change. Simultaneously, such claims were overlaid with an assumption that in the search of a better tomorrow, the insights of all cultural traditions and value systems were to be deemed obsolete. In the novel glow of psychedelic illumination, the wisdom of history was left to dissolve into acid dreams of creation without work and revolution without revolt. But by disregarding the legacies of the world's ancestors, the counter culture was left to devise new worlds without well-worn tools that had been honed through centuries of human development. Without a revolutionary foundation to stand on, the psychedelic era floated in a sea of excitement and romantic ideology. So while Leary's offerings inspired many people to get sky high in the search for a better view of tomorrow, none ever landed in the utopia promised when they came down from their trip beyond the world of the here-and-now.

Though the effects of psychedelics and their associated high hopes may have informed some of the people's movements of the 1960s and 70s, they weren't the main cause of the era's greatest successes. Many of the most long-standing changes of the time were won through physical struggle and direct opposition to the state by revolutionary organizations such as the Black Panther Party and Young Lords Party, a clear contrast to the positive thinking often promoted by psychedelic advocates of the time. In this time when physical resistance to the destruction of the world and its people was most needed, psychedelic pacifism excused removal from the labor of grassroots struggles with a hope that, somehow, things would change of their own accord.

Leary's famous saying was actually given to him by the media analyst Marshall McLuhan. McLuhan offered Leary psychoanalytical advice to help advance Leary's psychedelic campaign. It was with McLuhan's methods, reflective of the marketing techniques developed by Edward Bernays in the earlier part of the century, that Leary was ultimately successful in developing his emotionally charged rhetoric and iconography to sell the idea of a "psychedelic revolution."[26]

Psiloc(yb)in in the 21st Century

As the 70s passed, so too did the novelty of the psychedelic state as it eventually became just another offering by the world's drug dealers. Then, in the late 1990s, the rise of the internet and several pro-psychedelic authors pulled the effects of psychoactive fungi out of the fringes and back into subcultural spheres of influence.

As these drugs were revisited, so too was their potential medical benefit. Several human trials with psilocybin were granted government approval in the United States to investigate the effects of psilocybin, while organizations such as the Heffter Institute and the Multidisciplinary Association for Psychedelic Studies (MAPS) were established to validate these and other psychedelic studies.

The most consistently reported medical value of psilocybin is found in its effects on cluster headaches, a debilitating (and at times suicide-inducing) condition that affects up to 250,000 people in the U.S. Where Western medicine has continued to offer no cure for the afflicted, consumption of just a single subhallucinogenic dose of psilocin-containing mushrooms regularly induces remission of these headaches in some sufferers for months at a time.[127]

A study from 2014 showed that psilocybin can increase communication between normally unconnected areas in the human brain in an effect likened to synesthesia.[128] In another study, mice under the influence of psilocybin exhibited a decreased fear response to previously traumatic stimuli, suggesting the compound may serve as a novel approach to treating post-traumatic stress disorder (PTSD) in humans.[129]

Psilocybin has undergone one preliminary study to assess its potential in reducing the symptoms of obsessive-compulsive disorder (OCD) with doses as low as 25 mcg/kg. Though one patient in this study remained symptom-free for five months, the experiment has been criticized for its small sample size, lack of a control group, and short (24 hour) duration.[130] Caution should be exercised in justifying the use of psilocybin for people with OCD, as a small percentage of sufferers are known to occasionally have flashes of violent imagery, which could potentially be aggravated by a psychedelic experience.

Research into using synthetic psilocybin to reduce the "profound existential anxiety and despair" associated with advanced-stage cancer diagnosis has been recently performed at John Hopkins University in Baltimore. Under controlled conditions, and with the pre-direction and supervision of psychologists, terminal cancer patients who had been placed under the effects of psilocybin later claimed to have significantly reduced feelings of anxiety associated with their illness. Further, many stated they experienced an increased quality of life as they now saw great value in the limited time they had left to live.

Lastly, in a study similar to the 1962 Good Friday Experiment, researchers from John Hopkin's University's Heffter Research Institute administered varying quantities of psilocybin along with a placebo to 52 psychedelic-naïve participants to measure the drug's "spiritual" effects on the user. Similar to the Good Friday Experiment, the effects of the drug were quantified using a 32-question "Mysticism Scale." In this case, the survey was administered seven hours after the patients received their dose. That is, the patients were still likely under the effects of the drug to some degree when they were told to complete a relatively long theological questionnaire. In this immediate survey, as well as in follow up interviews 2 and 14 months later, a majority of patients reported positive experiences under the influence of administered psilocybin, leading the study's researchers to conclude that the synthetic compound could induce "mystical-type experiences" under controlled settings and with proper pre-conditioning of the patient.

A wide range of anecdotal accounts can be found online and in psychedelic circles that proclaim a striking array of other benefits from working with psilocin mushrooms or synthetic psilocybin. However, considering that the limited number of contemporary physiological and psychological studies with psilocybin are largely preliminary in their findings, founded on the effects produced under highly regimented "sets and settings," and/or based on a small sampling of patients, conclusive statements regarding the physical, emotional, or psychospiritual value of psilocybin are, in my opinion, not currently possible.

Psychedelics in Perspective

Reflecting on the above, the seemingly endless penetrations of psychoactive mushrooms into the heart of human history can often leave one feeling elated or overwhelmed. Such a deep and ancient kinship among humans and these few fungi has created a potent legacy. Today, the psychoactive mushrooms seem perplexing in their effects, alluring as potential catalysts, sacred through their presented rituals, and timeless by their influence.

However, if one wishes to determine how psychedelics can influence movements for social change, the many suppositions that have been made about fungi's cultural value must be balanced against the actual outcomes of their past use. For if an unbiased and thorough investigation reveals that such suppositions are flawed, then any current conclusions about the cultural significance of psychoactive fungi should be revisited and/or reframed until the discrepancies are clarified. Though a more ancestral dimension to these mushrooms has been presented thus far, a deeper analysis of the counterproductive aspects of psychoactive fungi must also be provided.

R. Gordon Wasson and the Mazatec Affair

The corruption of the Mazatec mushroom tradition that developed as a result of the Wassons' *Life Magazine* and *This Week* articles was not the only negative consequence of the reintroduction of psychoactive fungi into the Western world. Nor did the appropriation and misrepresentation of the Mazatec culture begin with the crowds of beatniks that flocked to southern Mexico in the late 1950s. The misuse of Maria Sabina's knowledge and her people started many years earlier when Gordon Wasson came to Mexico in search of a story. To best understand the motivations and means by which Wasson popularized his accounts in Mexico, it is helpful to first explain his history as a writer.

In 1941, after years working as a magazine journalist, Gordon Wasson wrote one of his first books, *The Hall Carbine Affair: A Study in Contemporary Folklore*.[131] In it, Wasson attempted to disprove accounts that the bank J.P. Morgan gained its initial fortune by knowingly selling the U.S. government carbine rifles that had been poorly manufactured. Soon after, Wasson was given a high-ranking job at J.P. Morgan Bank in the Wall Street district of New York City as the Vice President of public relations, the emotion-based marketing strategy designed by Edward Bernays.[132] As a member of the New York elite, Wasson is known to have been good friends with Bernays for over a decade, likely learning ways to refine his ability to sell ideas to the public along the way.[133] It was with the affluence that came from his high-ranking job that Wasson was able to afford his initial trips to Mexico and abroad in search of information about psychoactive fungi. And with his skill set as a publicist, Wasson was adept at crafting sensational stories that would appeal to large demographics.

Upon reviewing the book *Persephone's Quest* and reading Maria Sabina's biography, it is clear that Wasson's velada with Sabina did not happen by chance. When Wasson first came to southern Mexico, he was in search of a curandero/a that worked with mushrooms. But, being an outsider with no connections to the locals, he convinced a local mayor to help him find someone who both worked with psychoactive mushrooms and would allow him to participate in their ceremonies. After finding several such healers, Wasson eventually chose to work with Sabina and made arrangements to have their session photographed for later publicity. In her autobiography, Sabina states that she would have never worked with Wasson if he had not appeared to be on official business with the mayor. For her, the mushrooms were not used for novelty or even spiritual growth but, rather, for more practical matters such as physical healing from diseases or for finding lost objects. Wasson was in need of neither of these services. Further, Sabina was a devout Catholic who saw the church as her place of worship—she never used the mushrooms for spiritual purposes.[134]

And yet, when Wasson wrote his article for *Life Magazine*, the reality of Sabina's relationship with the mushrooms and the means by which the velada was arranged were replaced with a sensationalized account and a pitch to promote Wasson's upcoming book, *Mushrooms, Russia and History*.[135] Wasson's misrepresentation of the mushroom practices of Huatla de Jimenez was, in short, used to help him sell a book and build a reputation for himself as a mycological "expert."

Outsiders soon came to Huatla in search of Maria and her mushrooms. At first, Sabina worked

I am a woman who waits, says
I am a daylight woman, says
I am a moon woman, says
I am a Morning Star woman, says
I am a God Star woman, says...
I am the doctor woman, says
I am the herb woman, says...
Our woman of light, says
Our saint woman, says
Our spirit woman, says...
I am a lord eagle woman, says
Our woman who flies, says...
Our woman who looks inside of things, says
You are the saint, says
You are the saintess, says...
I am a woman wise in medicine, says
I am a woman wise in words, says
I am a hummingbird woman, says
Whirling woman of colors, says
Woman of the sea, says...
—Maria Sabina

with these foreigners for free until, following the advice of family members, she soon began taking the money they offered. In time, the insertion of money into this traditionally gifted healing practice stained Sabina's reputation in the local community. As outsiders came to plunder the area's hillsides for *Psilocybes*, Maria soon found that the mushrooms had lost their healing power as their connection with her faded. To quote her directly,

> *"From the moment when the strangers arrived the 'Holy Children' lost their purity. They lost their strength. They were profaned. From now on they will serve no purpose. There is no help for it. Before Wasson, I felt the mushrooms exalted me. Now I no longer feel this...from the moment the strangers arrived...the mushrooms lost their purity. They lost their power. They decomposed. From that moment on, they no longer worked."* [136]

At the end of her life, Maria Sabina died poor, rejected by her community of healers and stripped of the mushrooms she had worked with since childhood. As her village became a tourist attraction for drug enthusiasts seeking a "real taste of Mexico," the mushrooms (her *niñitos* or "little children") were exported around the world and cultivated en masse by people who had little understanding of the tradition they consumed.

Psychedelic Mind Control

Although psychedelics had yet to be regulated in the 1950s, research into their mind-altering effects did not go unnoticed by the U.S. government. Soon after the discovery of LSD, intelligence agencies began investigating the drug's potential use as a new tool for manipulating the thinking and behavioral patterns of enemies. Prior to the discovery of LSD, the CIA had worked for decades with a wide variety of drugs and behavior modification techniques to determine the extent to which the human mind could be externally influenced and controlled. The discoveries of LSD and psilocybin greatly expanded this research by offering novel insights into how humans can perceive and interpret the world. Known today as MKULTRA, this operation was heavily classified throughout the 20th century until a series of U.S. Congressional hearings in the 1970s exposed the tragedies of this government-sponsored psychological warfare.

The few documents that remain of the declassified history of MKULTRA are filled with accounts of government agents using psychedelics on unwitting people to discover means for "depatterning" the human mind. In one report, LSD was administered for 174 days to a mental patient in Kentucky.[137] In another infamous case from August 16, 1951, the CIA extended their research from individuals to a whole village in Pont-Saint-Esprit, France. Here, CIA agents secretly laced bread loaves with LSD, leading to widespread hallucinations among hundreds of villagers, dozens of people being locked in mental asylums, and five deaths. For decades the bizarre "Cursed Bread" incident was blamed on mercury or Ergot poisoning until it was uncovered that foreign operatives constructed the entire scenario.[138] While the CIA claims that research into the weaponized use of LSD and psilocybin was abandoned, it is hard to imagine that the agency was unable to develop any applications for two powerful compounds that make their user highly suggestible and susceptible to outside influence.

MKULTRA's Subproject 58

In recent years, researchers into the history of MKULTRA have claimed that an outside CIA agent seeking access to psychedelic mushrooms infiltrated Gordon Wasson's 1956 Mexico trip. The most commonly presented story in this regard is that a CIA agent by the name of James Moore entered Wasson's team by offering technical support as a chemist. He is also said to have supplied financial support to the team in the form of a $2,000 grant from the Geschwickter Fund, which was later revealed to be a CIA-backed institute. This infiltration, known as MKULTRA's Subproject 58, is claimed to have provided the CIA with their initial source of psilocybin.

Jan Irvin's Revision of Modern Psychedelic History

As noted earlier, in *The Holy Mushroom*, author and ethnomycology researcher Jan Irvin sought to unravel the attacks launched against John Allegro by Gordon Wasson. Since the book's publication in 2008, Irvin has continued to investigate other untold legacies of Wasson, often treading where no researcher has gone before him. Irvin's investigation—built largely on primary documents directly written by or to Wasson—has since shed light on numerous secrets of this mycological legend. By gathering letters from the personal archives of public figures associated with Wasson as well as documents obtained through Freedom Of Information Act requests to the CIA and other government agencies, Irvin has been able to essentially fill in the unwritten biography of Gordon Wasson. Among his many discoveries, Irvin has found that:

- Wasson knowingly participated in significant academic fraud during his writing of the *Hall Carbine Affair*. Wasson secretly worked with an academic historian to create an artificial version of history that covered up the reality that J.P. Morgan bank did in fact gain its initial fortune by swindling the U.S. government with faulty rifles.[139]
- Wasson plagiarized many of his ideas in *Soma* from an 1892 book on Scatology by John G. Bourke, in which Bourke dedicates more than 30 pages to ritualistic mushrooms use, including *Amanita muscaria* urine-drinking customs in Siberia and Mexican mushroom practices.[140]
- At J.P. Morgan, Wasson managed the account for the Pope and Vatican.
- Wasson served as a chairman to the Council on Foreign Relations and was heavily involved in the Century Club, an elite organization attended by many powerful public and military figures.
- Wasson was close friends with Allen Dulles, head of the CIA, and had ties to many other high-ranking military officials.
- It was Wasson and not James Moore who requested the $2,000 grant from the CIA to help fund psychoactive mushroom research in Mexico.[141]

In other words, Wasson was not simply a "banker" turned amateur mycologist, as is so often presented. Rather, the man held significant power and influence amongst many powerful figures around the world and worked directly with the CIA during his trips to Mexico.

When Irvin first presented his research to the psychedelic community in 2012 he was immediately ridiculed for contradicting over 50 years of popularly accepted history. In short time, Irvin was ostracized from the psychedelic research community that he had been heavily involved in for over 20 years for nothing more than disproving popular beliefs with documented evidence. Psychedelics advocates continue to criticize Irvin's work for the controversy it evokes even though, as Irvin claims, none of these critics have ever looked at the primary documentation underlying the research nor have any of Irvin's claims been disproven.

When I first heard of Irvin's work, I was surprised to hear such a contradictory account of the contemporary history of psychoactive fungi. But considering the profound implications that such claims hold in relation to any discussion for integrating psychoactive fungi into theories on social change, I decided to not dismiss them outright but to investigate their validity, so as to decide for myself.

In early 2014, I contacted Irvin to see if he would be willing to review a synopsis of his research that I had written for *Radical Mycology*. I told Irvin I wanted to offer the reader an unbiased account of the commonly presented history of Wasson's work alongside Irvin's version, so as to let the reader decide which was more accurate. Irvin responded that, due to his conviction in his research's integrity, he would rather offer me access to his home and research documents in southern California so that he could most clearly explain his findings.

So, in June of 2014 I travelled to the hills outside of Los Angeles to see the documents on Wasson that Irvin had diligently accumulated over the previous eight years. Throughout an entire day together, Irvin walked me through the string of evidence showing me the documentation of

Tolstoy had said the printing press was a mighty engine for disseminating ignorance. This Mazatec affair is a case in point.
—Gordon Wasson, letter to Bertram Wolfe Oct 13, 1970.

Wasson's elite affiliations, letters directly from Wasson to the CIA and Allen Dulles, and even a letter in which Wasson bragged about deceiving the general population. In the end, I had to conclude that the above claims Irvin made about Wasson were true and that the entire foundation of the psychedelic subculture I had variously engaged with throughout my life was now called into question.

The Revolutionary Extent of a Psychedelic Movement

Since his initial exposé on Wasson in 2012, Irvin's website and podcast, Gnostic Media,[142] has become an archive of interviews and primary data that further call into question the outcomes and motives of the 1960's psychedelic era. Much of this work revolves around an assertion that though psychedelics have been repeatedly promoted as tools for initiating mass social change, the actual outcomes of their widespread use have been manipulated by government intervention to lead the psychedelic movement far from achieving any true social reform. Just as the Black Panther Party was sabotaged by the FBI's Counter Intelligence Program (COINTELPRO) and the CIA's introduction of heroin and crack cocaine into the ghettos of major U.S. cities,[143] Irvin claims his research proves that government agents helped promote psychedelics in the revolutionary movements of predominantly white middle class groups as a destabilization tactic to reduce drives for direct and/or violent confrontation against the state apparatus. A full analysis of Irvin's research is not possible in the space left in this chapter, so the reader is encouraged to follow up on the many other facets to these and other claims laid by Irvin and his colleagues in order to form a complete understanding of these conclusions.[144] Regardless, it is not necessary for one to agree with all of Irvin's conclusions to assess how the use of psychedelics over the last few decades has hindered the progress of revolutionary social movements.

Such setbacks can also be attributed in part to the many speculative theories that have been presented about the potential influence that psychedelics could have on human cultures. Just as McKenna's "Stoned Ape Theory" attempted to imbed a psychedelic influence within the origins of modern human consciousness, many contemporary psychedelics advocates claim that the widespread use of psychoactive substances could catalyze a "consciousness evolution" in Western culture, leading to a release from the world's destructive and patriarchal social hierarchy. However, for as appealing as such a simple idea may be, it does not account for the deeply imbedded conditioning that has kept humanity from *soberly* breaking its chains over the eons.

Some of the primary causes for widespread acceptance of a regimented, reductionist, and divisive social order is not rooted in a natural desire among humans to create an unlivable planet for future generations. Rather, constant acts of imperialism by industrialized nations, the exploitation of the planet, capitalism, the systemic suppression of the feminine principle, and the cultural oppression of women, Indigenous people, people of color, and other marginalized demographics has led to many of the most pressing issues facing the world today. These facets of social control are enforced through the threat of violence and imprisonment underlying the state apparatus and relentlessly justified through homogenized education and media systems that emphasize unsustainable values and impede an individual's ability to command their life.

Psychedelics may help one realize that such flaws exist in modern culture, but they cannot readily dissolve the influence of this social engineering within an individual. Nor can a subjective experience on psychedelics destroy external institutions of control. This is likely why many people who consume psychoactive substances fail to ever integrate the positive insights they uncover during a psychedelic experience.

The Land of Youth is now also the Land of the Dead. Utopia recedes into time and space, which are now experienced and defined as dystopian, as a vale of tears, and a realm of becoming and corruption.
—Peter Wilson[145]

The dominant culture's power is maintained by such an overwhelming array of visible and invisible tactics that to confront their influence can leave one feeling ineffective and powerless. If a person or culture lacks the internal strength, mental conditioning, and cohesion to face the daunting task of creating a healthier and more venerable world, it can be seemingly impossible to know where to begin. From this existential position, the psychedelic experience is appealing. Where the challenge of facing one's personal shortcomings and the megalithic pillars of the dominant culture loom as impenetrable obstacles, dissolving eons of social constrictions has fallen for some onto the allure of the psychedelic mystique. But to sense such an alternate reality is not the same

as manifesting that world in the average state of being; ideas are not actions until they are enacted.

In effect, psychoactive fungi have come to serve as a silver bullet that can destroy even the deepest cultural and psychological imbalances and replace them with a bandage of imagery. But though these fungi can help instigate remediation and regeneration cycles in the damaged landscapes of the human psyche, they cannot work in isolation; the human mind, body, and spirit must also be involved. By placing personal responsibility onto the psychedelic mushroom experience, one loses the chance of finding an inner source of strength and to connect with their innate healing potential.

As it stands, the vast majority of the world will likely never afford, discuss, or appreciate psychoactive substance. This point presents a challenge to the psychedelic liberation argument, as an assertion that these drugs' subjective effects are a solution to social problems can be hard to understand by psychedelic naïve people working in social and environmental causes. In effect, the extremes of the psychedelic culture become highly segregated from most facets of society—whether mainstream, alternative, or revolutionary—reducing any potentially positive influences that psychoactive fungi could have on cultural change.

As long as psychedelic rhetoric places its emphasis on theorizing about social change and away from crafting tangible solutions, the potential for any social progress to derive from altered states will remain untenable. In the psychedelic milieu, drugs have become a brick launched against the shuttered windows of institutionalized perception. They symbolize the common struggle for purpose and expanse beyond the status quo by offering the user an easy means to gently shake the walls of culture, while ignoring the fact that true revolution must crack the foundations of the past and actively work to build a better tomorrow. To integrate these substances into any effort for social change must be done in a manner that reflects the context of society's various challenges and also respects and acknowledges the range of impacts these fungi can have on their consumer. To do otherwise would not only be short-sighted, but would also undermine the strength that each person holds to radically change their world without the influence of a psychedelic experience.

The Revelations of a Psychedelic Moment

All of this is not to say that psychoactive fungi offer nothing to a person seeking an alternative from the constrained definitions of modern life. Under certain circumstances, the effects of these fungi can be described as a temporary alteration of one's perceptual filters. Often, one can feel more objective about their experience of the world, providing some space to confront assumptions about themselves and the world. Under the mushroom's grip, the user often takes on an indescribable feeling—a knowing—of hidden layers to their inner world and the outer universe, and to a state where human potential seems unlimited. Previously unknown forces can seem to stream into the user's sense of environment and conscious subjectivity. In natural spaces, one may feel a resonance with other beings, an endless and profound love from and for Nature, and a uniting cause woven throughout the whole of the universe. With a veil lifted, one may sense, perhaps for the first time in their life, that they are a part of Nature's implicate order, and not apart from it. And if the limitations of cultural conditioning continue to dissolve, the safety shield of ego may be lowered, enhancing one's ability to objectively observe life, language, and one's true self hidden beneath a lifetime of false perceptions.[146]

The psychological unraveling of psilocin awareness is perhaps the most significant aspect of the entire experience. Under psilocin, as with many other non-drug-based altered states, the user may be brought to a rare state of self-reflection that is absent from most discussions on health and healing. Exposing the darkest corners of one's psyche, buried traumas from one's life may be drawn to the surface of mind. This revelation may lead to a rapid and challenging confrontation with the suppressed aspects of identity, or what psychologist Carl Jung called the shadow self. Piercing the ego that blocks access to these buried elements of mind, the mushrooms can thus provide a rare glimpse into the reasons behind one's negative traits and habits and offer a chance to begin a healing process based on the insights uncovered.

We meet ourselves time and again in a thousand disguises on the path of life.

—Carl Jung

From these short insights, the astute user must then be willing to confront the coming years that are required to truly make use of such lessons. For if the mushroom experience is said to have

made any real impact, it will likely only come through the direct and challenging work of addressing and healing one's psychological wounds in that person's average state of consciousness. Experiences of the altered states—especially those removed from a traditional context—cannot enable one to overcome their destructive habits; they can, at best, only reveal where to begin. Such work, while never easy, is necessary for personal evolution. Without integration with their unexamined aspects, the individual stands to live stifled by inner turmoil and disconnected from their greatest ambitions.

When one learns to recognize the pain they inflict upon themself and others, they are offered a chance to disrupt one of the greatest hindrances to the progress of humanity: the invisible transgressions laid daily by friend to friend, parent to child, lover to lover. When humans suppress their desires, they inevitably expel their internal frustrations upon the easiest target available. But when the full self is realized, a more authentic and peaceful life can be found. As Jung so often claimed, if any person fails to do their shadow work, all suppressed divisions will surface through the endless forms of destruction that people unleash against themselves, their peers, and symbols of power. All such acts can be argued to be externalizations of an angst that arises from a denial of self-knowledge.

In the world's Nature-based traditions, a variety of rituals, dances, and ceremonies have been developed over generations to balance the internal archetypes and purge the participant's minds of their suppressed emotions. In this way, one's shadow self can be more readily embraced as a partner in the challenges of survival and human relationships. Such a connection to, and constant communication with, the shadow was found to serve many traditional cultures long ago. By raising one's awareness of their inner demons, the individual was found to strengthen their sense of self and become a more honorable person through an increased certainty of moral intent. Such acts of cleansing and reconnection to center lie at the foundation of so many Nature-based spiritual practices. This is likely why so many of these cultures did not need to engage with psychoactive plants or fungi: this healing could come through a variety of means. For those cultures that did work with psychoactive substances, it was often not the plant or mushroom that lay at the center of ceremony but, rather, the altered state where the healing took place; how one got to that state was less important than the state itself.

In the absence of culturally sanctioned states of altered consciousness or transformational rites of passage, modern life has become a constant sprint from individuality. The altered state reminds one of the value in the individual experience. It holds the legs of the racing mind, slowing thoughts to demonstrate how each person runs from themself and the beauty of life that flows through all moments. For all its potential shortcomings, the altered state can be experienced as a glimpse into underlying order within a universe that is so often presented to be random, entropically dying, and without meaning. Modern science offers little in the search for a reason for living; to the reductionists, all answers are said to await discovery in yet to be deciphered equations. In contrast, the altered state can help one question preconceived notions on the nature of reality, suggesting new paradigms that await discovery and the possibility that the conclusions of modern science might need reassessment.

The challenge that this state places on the user is to ensure that one's ability to assess the average experience of the world is anchored with the tools of intellectual discernment. The existential questions that the psychedelic experience produces must not dismiss the need for critical analysis of normal states. To do otherwise would be to deny the notion that one can prove that a tree is a tree or that the heart pumps blood. While the altered state questions what one believes, one must remember that they *can* know things for certain in the normal plane of existence and that not all things are relative. The skill that must be learned, then, is not just how to ask the right question but how to also develop a *personal* means for discerning coherent answers about one's perspective on the world.

This is the path of self gnosis, one that begins by asking questions and, for the devout, leads to the realization of an authentic life. The altered state can start the individual down an alternate route in life's road, but the journey one makes must always be recognized as an individual pursuit and should, in my opinion, be a mostly sober one. If one wishes to honor the insights gained in the altered state, they must recognize the command to full self expression that lies at its foundation. For though one's connections to kin and culture is integral to maintaining a sense of tradition, de-

veloping personally important customs, and learning from the past, constantly defining one's life by the whims of others is the antithesis to personal progress. Such seeking of approval in its variety of forms is part of what has led humanity to its current state of imbalance. On the road to selfhood, then, one must develop an inner compass to navigate the challenging terrain of life, and release dependency on the tattered maps others have drawn to guide their own way through the shifting sands. Under certain cases, the altered state can offer a glimpse of a self freed of dependency on a master above and healed of the drive to command a slave below. Still, it is ultimately up to the user to determine what, if anything, of the insight is worthy of pursuit.

Closing Spores

For all of the claims made to the limits of human awareness throughout history, the origin of consciousness has still yet to be resolved. As neurologists seek to find the seat of the soul in a specific gland or region of the brain, some studies have led to the suggestion that, rather than being the creator of consciousness, the human brain may be more like a receiver of a field of consciousness that exists beyond the body.[147] Under such a framework, the brain may be likened to a television set that, under a range of circumstances, can shift its "station" from an average state of perception to another state in which information that is generally undetectable can be perceived. Such proposals inevitably lead to unresolvable questions about the nature of reality, the limits of consciousness, the structure of the universe, and the source of creativity and intuition. And, for the socially minded observer, they also raise questions about the influence of psychedelics on cultural design.

The television does present a strong analog to the psychedelic experience. Both project images into the mind of the viewer that influence one's later perception of the world and affect the subconscious in ways that are difficult, if not impossible, to measure. Psychedelics are like a channel changer for the mind, flipping through an infinite number of stations. Some channels may be filled with recollections of the past, others with live feeds into what seem to be alternate worlds. Some contain chaotic or frightening imagery, while others may relay complete fictions crafted by the personal unconscious of the user, the collective unconscious of humanity, or by other, unknown designers. Trickier still, it may be hard for the viewer to discern which type of station they are on, even after hours absorbed in the presentation. And yet, the unusual realities created by television or psychedelics are used to influence the rest of life, creating belief systems, idols, and whole cultures based on projected imagery that are often far removed from one's daily experience of Nature and reality.

In many ways, the television could have been a truly wonderful invention; with its ability to educate and inspire, TV has the potential to foster a culture of high values, aesthetics, and aspirations for the benefit of all humankind. It is unfortunate, then, that this tool has instead been largely used to perpetuate consumerism and the interests of an elite few. In a similar way, one finds the potential for psychoactive fungi to both uplift and distract, to offer insight or tint the world with fleeting hallucinations.

In the book *A Brave New World*, author Aldous Huxley describes a dystopic future where government sponsored drug use enables a global caste system to be blissfully accepted by its members. The book was a warning of the potential for governments to use drugs as a means to control an uninformed population through the augmentation of social perceptions. And yet, despite the book's popularity in psychedelic circles, many advocate for government approval of the clinical administration of synthetic psilocybin. This step toward psychedelic legalization can be initially appealing, however underlying it is the potential for state regulated practices to define how whole societies understand the psychedelic experience, let alone how one works with it for personal growth.

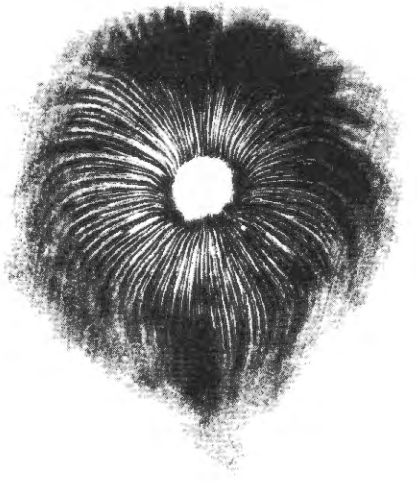
Considering how refined and integrated the practices for navigating altered states have been in many of the world's traditional cultures, it is difficult to imagine that state-controlled administration of psychedelics could ever compare to the depth of these customs. By removing all traditional contexts from the experience, the container supplied by psychedelic clinicians would only be able to extend to the depth of the therapist's training. Patients lacking a traditional understanding of the substances would thus be left at the whims of the psychedelic interpretations supplied by the medical establishment and the governmental institutions that design their protocols for administration.

In such a vision of the future of psychedelic use, the state apparatus would be the key holder to an entire culture's experience and interpretation of altered states of consciousness.

In lieu of this, the abolition of the War on Drugs may be the most effective measure for ending the negative economic, ecological, and cultural impacts that result from restrictions on drug use. Admittedly, such a shift in the current social order would result in notable changes in the use and influence of drugs in modern cultures. However, as many advocates for abolishing the War on Drugs have noted, the long-term effect of decriminalization will be a healthier and less crime-oriented world.[148] The War on Drugs is ultimately nothing more than a war on the spirit of humanity as it strips individuals of their right to choose how they perceive reality, their world, and determine the course of their own life.

In the end, such acts underlie a War on Consciousness that, if left unabated, could lead to the collapse of a multiverse of potential realities into a globalized view of life as a closed system without meaning. As the world now awakens to shake these and other foundations to the social hierarchy, the fungi return to cultural awareness, offering a glimpse into a forgotten past. The mushrooms have held a central role in the development of human cultures; they were revered, exalted, and deified by humans of the past. Yet today many are unaware of their impact on history or their potential to influence the future of humanity. It is time to change our understanding and know the fungi again.

With modern culture's increasingly disconnected understanding of the past, it is imperative for all social theorists, activists, change makers, and mycophiles to develop a personal, yet well-informed opinion of psychoactive fungi—and, for that matter, all fungi—through a sound investigation of their complex history. With so many opinions surrounding these fungi, it may be impossible to truly examine the altered states they produce unhindered. However, the choice to intepret or experience these substances should always be left to the individual. I just hope that such choices are made with the principles of *Radical Mycology* held in mind.



Species Profiles

Non-Cap and Stalk

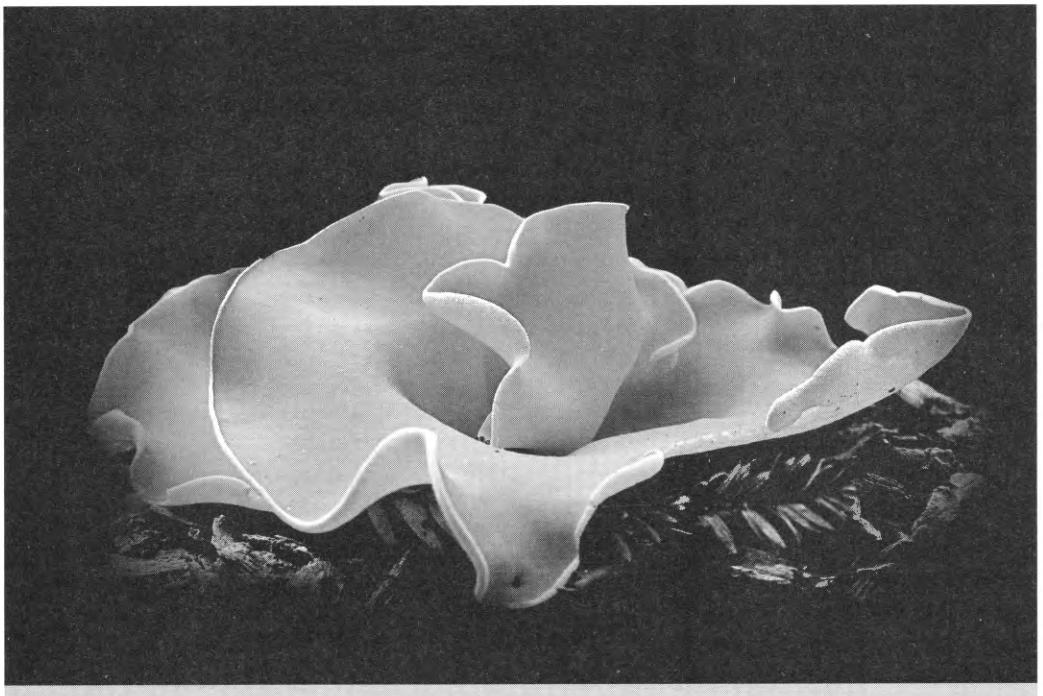
Aleuria aurantia (Pers.) Fuckel

Orange Peel Fungus

Spores: 18–24x9–11 µm, elliptical, reticulated/ridged when mature, often with two oil drops. **Stalk:** Absent/rudimentary. **Cap:** 1–10 cm broad, round/cup/saucer-shaped, flat/wavy/irregular, upper inner surface bright orange/golden, smooth/slightly downy, producing a spore cloud when disturbed, flesh thin/fragile, no odor or flavor.

Range: Very common, across North America, Europe, Chile. **Ecology:** Bare soil/sand, roadsides, paths, landslides, grass, and moss. **Growth Habit:** Scattered/gregarious/in fused clusters. **Season:** Spring–winter.

Edibility: Yes—thin and fragile, very little taste. **Other:** Decoctions traditionally given to cows with colds in Europe. Needs sunlight to produce color.



N.1 – *Aleuria aurantia.*

Represented species

Aleuria aurantia
Auricularia auricular & A. polytricha
Bjerkandera adusta
Bridgeoporus nobilissimus
Cerrena unicolor
Chondrostereum purpureum
Claviceps purpurea
Daldinia concentrica
Echinodontium tinctorium
Fistulina hepatica
Fomes fomentarius
Ganoderma applanatum
Ganoderma tsugae
Ganoderma lucidum
Gloeophyllum sepiarium
Grifola frondosa
Hericium erinaceus
Heterobasidion annosum
Inonotus obliquus
Irpex lacteus
Ischnoderma resinosum
Laetiporus sulphureus & allies
Morchella angusticeps & allies
Phaeolus schweinitzii
Phallus impudicus
Phellinus igniarius
Phlebia tremellosa
Piptoporus betulinus
Pisolithus tinctorius
Podaxis pistillaris
Polyporus umbellatus
Pseudohydnum gelatinosum
Schizophyllum commune
Serpula lacrymans
Sparassis radicata
Stereum hirsutum
Terfezia arenaria
Trametes versicolor
Xylaria hypoxylon
Xylaria polymorpha

Auricularia auricula (Bull.) Quel. & *A. polytricha* (Mont.) Sacc.

Wood Ear, Tree Ear, Jelly Ear, Jew's Ear, China: *Yung Nge* (A. auricula), *Mo Ehr, Muk Nge* (A. polytricha), Czech: *Ucho Jidásovo,* Dutch: *Judasoor,* French: *Orielle de Judas,* German: *Judasohr,* Italian: *Orecchio Di Giuda,* Japan: *Kikurage,* Polish: *Uszak Bzowy,* Russian: *Ioodini Ooshi,* Spanish: *Oreja de Judas. A. polytricha*: Wood Ear, Yu Er, Moamuer, Yung Nao, Muk Ngo, Kikurage, Mokurage

Spores: 12–18x4–8 µm, sausage-shaped/cylindrical, smooth, white. **Stalk:** Absent/rudimentary. **Fruit Body:** 2–15 cm, rubbery/gelatinous, hard when dry, broad, cup/ear-shaped/with ear-like lobes, outer surface sterile, often veined/ribbed, silky/hairy, reddish-brown/pale-brown/liver-brown/blackish.

Range: Very widely distributed throughout Asia, Australia, Europe, and North America. **Ecology:** On logs/dead branches/stumps of conifer/hardwood (oak/willow/locust/mulberry/sycamore/beech/ash/locust-acacia/elder), on eucalyptus in Australia. **Growth Habit:** Solitary/groups/clusters, attached centrally/laterally. **Season:** May–June, Sept–Dec.

Edibility: Yes—common in *mu shu* pork. 8–10% protein, 84–87% carbohydrates, 9–14% fiber. **Medicinal:** Decoctions good for sore throat. Applied to styes and infected eyelids. Balances pancreatic secretions and helps regulate glycogen production and storage. Lowers blood sugar and cholesterol. Antihepatitis, antimutagenic, anti-aging, antiviral, anticancer, stimulates immune system. May help with birth control by preventing egg implantation. Replenishes energy, improves circulation. Helps after childbirth with blood clotting and inflammation, hemorrhoids, immune response, and angina. An MAOI. Rogers suggests 15 grams decocted/powdered, 2x/day. In Traditional Chinese Medicine: lightens and strengthens the body, strengthens the will, for post-partum bleeding, stomach tonic. Stir fried, boiled until soft, then served with brown sugar for irregular uterine bleeding. **Other:** Twenty-two primates eat it. Goeldi's Monkey from South America spends 63% of its life eating it and other fungi.

N.2 – *Auricularia polytricha.*

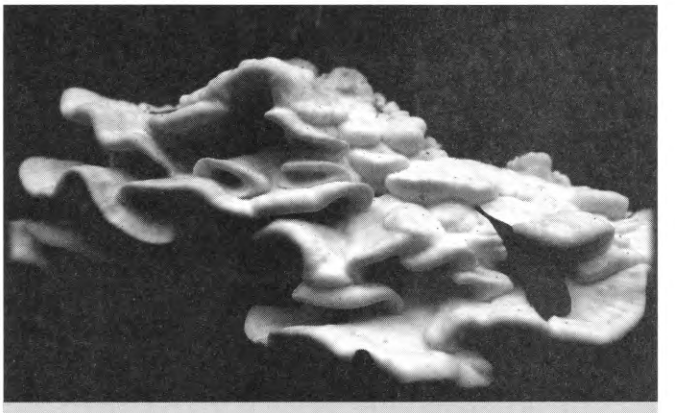
Bjerkandera adusta (Willd.) P. Karst.

Smoky Polypore

Spores: 4–6x2.5–3 µm, smooth, oblong/elliptical/cylindrical, smooth, white/yellowish. **Stalk:** Absent. **Fruit Body:** 1–7 cm broad, plane/wavy, elongated/fanned, white/tan/smoky/grayish-brown, dry, finely hairy/smooth, margin whitish/black, flesh 1–6 mm thin, tough, darkening in age, odor anise-like/fungal, taste sour. **Pores:** 5–7 mm wide, whitish/gray/blackish, darkening where bruised, tubes up to 2 mm long. Pore color a key identifier.

Ecology: A white rotter on dead deciduous/coniferous wood (oak/alder/chestnut). **Growth Habit:** Shelf/bracket-like, often fused in clusters. **Season:** July–Nov.

Edibility: Inedible. **Medicinal:** Antitumor, immunomodulating, antifungal. **Remediation:** Well researched. Highly effective against PAHs (anthracene [99.2%], benzo[a]pyrene), PCB cogeners, herbicides (e.g. chlortoluron [98%], diuron [92%], and isoproturon [88%]), styrene, and nonylphenol.



N.3 – *Bjerkandera adjusta.*

Bridgeoporus nobilissimus

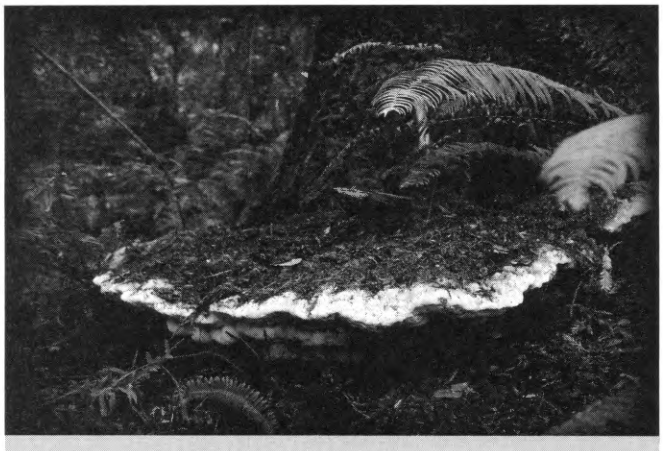
(W.B. Cooke) T.J. Volk, Burds. & Ammirati

Noble Polypore

Spore Features 5.5–6.5x3.5–4.5 µm, ovoid, hyaline, smooth, thin-walled. **Pores:** 2/mm, circular/angular, becoming pale brown in age. Tubes 2–7 mm long, tube layers separated by thin flesh layer, ivory/buff. **Fruit Body:** Perennial, massive shelves, fibrous, rubbery and tough fresh, hard and brittle dry, upper surface covered with coarse hairs, flesh ivory and corky.

Range: Rare and endangered, known only from forests of Washington, Oregon, and SW Canada. **Ecology:** On noble fir/pacific silver fir/western hemlock/maple/poplar.

Medicinal: Antitumor, antifungal, antibacterial, 38.5% beta glucans. **Remediation:** Shown to degrade 3 phenyl urea-based herbicides. **Other:** One of the few protected mushrooms.



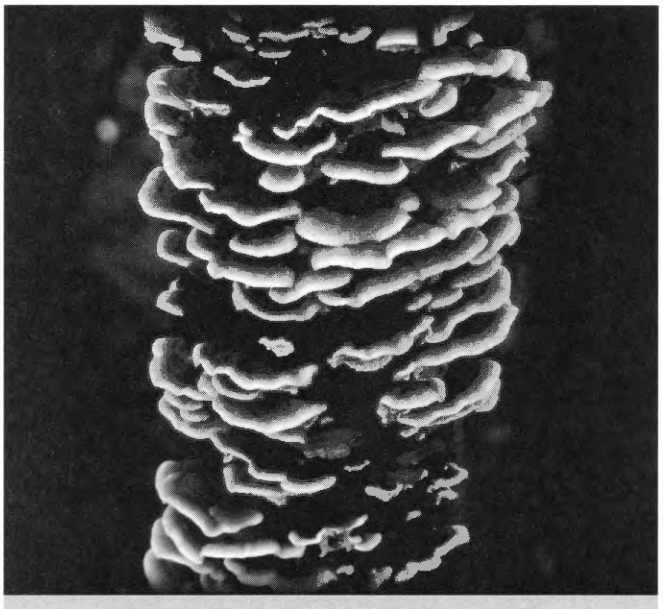
N.4 – *Bridgeoporus nobilissimus*, an endangered mushroom.

Cerrena unicolor (Bull.) Murrill
Mossy Maze Polypore

Spores: 4.5–5.5x2.5–3.5 µm, oblong/elliptical, smooth, white, hyaline, inamyloid. **Stalk:** Absent. **Fruit Body:** 0.5–7.5 cm wide, semicircular, wavy, flat, algae-covered, dry, white/grayish/brown/greenish, hairy, flesh 0.5–1 mm thick and white, with thin dark line separating it from cap. **Pores:** Maze-like, breaking up to form teeth. 2–3/mm, white/smokey.

Range: North America. **Ecology:** Deciduous wood. **Growth Habit:** Overlapping layers. **Season:** Year-round.

Edibility: Inedible. **Medicinal:** Anticancer, antibacterial.



N.5 – *Cerrena unicolor*.

Chondrostereum purpureum (Pers.) Pouzar
Silver Leaf Fungus

Spores: 6–8x3–4 µm, elliptical/ovoid, smooth, whitish. **Fruit Body:** 0.5–2x10–5 cm, crimped/lobed, hairy, purple/violet/dark brown, bracket-shaped, flesh thin, leathery, soft, and whitish.

Range: Worldwide. **Ecology:** On hardwood logs/snags/stumps (apple/plum/poplar/willow/maple/hornbeam/plane/oak/elm/lilac). Causes the progressive and often fatal silver leaf disease on apple and plum trees. Rarely on conifers. **Growth Habit:** Overlapping masses. **Season:** Can persist for years.

Edibility: Too thin and leathery to eat. **Medicinal:** Inhibits HIV-1 virus reverse transcriptase. **Remediation:** Extracts used to inhibit deciduous stump or cutting regrowth.

Claviceps purpurea (Fr.) Tul.
Ergot

Spores: Conidia 4–6x2–3 µm, white, septate, smooth. **Stalk:** Long, thin, smooth. **Sclerotia:** Globose head, ochre/brown/pale purple, spotted with immersed perithecia, elongated, cylindrical, grooved, outside dark, interior white and hard. Stromata emerge from the sclerotium when it drops to the ground.

Range: Europe, North America, and other parts of the world. **Ecology:** Sclerotia parasitic on the inflorescences of Gramineae. The fungus takes over the plant ovaries, forming sclerotia that overwinter, then produce small mushroom-like fruit bodies in the spring to infect crops. **Season:** Summer.

Edibility: Extremely poisonous. If accidently mixed in with ground wheat, rye, or barley it can cause violent a poisoning called ergotism (a.k.a. St. Anthony's Fire). **Medicinal:** Contains psychoactive compounds, see Chapter 12. Extracts (ergotine) used in allopathic medicine to constrict blood vessels. Elevated levels can damage brain cells and cause pathological disorder (i.e. Parkinson's disease). Can help improve blood oxygen to brain, increase intelligence, memory, learning, and recall. Helps with prostate problems, reduces lactation in women, ulcers, stomach cramps, diarrhea, paralysis of anal sphincter, uterus hemorrhage for post partum, slow labor, migraine headaches, and angina pectoris. Various pharmaceuticals are derived from its complex chemistry. In homeopathy: mother tincture is made from dried Ergot, successed 1–30C, used for numbness, gangrene, heavy menses, diarrhea, lack of bladder control, and many women's health issues. **Other:** St. Anthony was a North African desert hermit from the 4th century CE.

Cultivation: Intentional cultivation, harvesting, processing, or consumption of Ergot in any form is not recommended. There are no verified means for safe and easy consumption of Ergot or its products. Consuming the toxic compounds in Ergot can lead to gangrene and death.

DALDINIA CONCENTRICA (Bolton) Ces. & De Not.

Cramp Balls, King Alfred's Cakes, Carbon Balls, Coal Fungus, India: *Kala Pihiri* (Black Mushroom)

SPORES: Sexual spores are 14–27x6.5–11 µm, elliptical/elongated, smooth, dark brown/black. Asexual conidia minute, smooth, hyaline, white. **STALK:** Absent. **FRUIT BODY:** Tough/woody/charcoal-like mounds, 1–6 cm broad, hemispherical/round, lumpy, stalkless, pimpled by perithecia, cracked in age, black/dark brown. Flesh brittle, brown/gray-black, with concentric zones representing growth seasons.

RANGE: North America, Maine to Florida, Pacific NW, Chile, Africa, Europe. **ECOLOGY:** On dead logs/branches/bark of conifers/broadleaf (oak/ash). **GROWTH HABIT:** Scattered/gregarious in masses. **SEASON:** Perennial.

MEDICINAL: Antimicrobial, inhibits HIV-1. In Traditional Chinese Medicine: used for cramps and spasmodic conditions. Used in many other cultures. **OTHER:** Smoke calms bees. Powder can be fed to fish and livestock. Creates a purple pigment. Burns slowly. Releases spores at night: 2 billion released from 10 pm to 5 am, peaking at 11 pm.

ECHINODONTIUM TINCTORIUM (Ellis & Everh.) Ellis & Everh.

Indian Paint Fungus, Toothed Conk, Cree: *Meah Kis Igum*

SPORES: 5–5.8x3.5–6 µm, elliptical, spiny, amyloid, white. **FRUIT BODY:** 4–25 cm, hoof-shaped conk, woody, orange/cinnamon/brick red, zoned, upper surface black, dry, hairy, flesh leathery. **TEETH:** Brittle, blunt, thick, flat, 1–2 cm long, grayish/black.

RANGE: Western North America. **ECOLOGY:** Forms extensive white heart rot on conifers/western grand fir/Douglas-fir/balsam fir/western grand fir/western hemlock. **SEASON:** Perennial, spring–fall.

MEDICINAL: Contains several alkaloids and tannins. Anticancer, antimicrobial. **DYES:** See Chapter 3. **OTHER:** Considered a living fossil. The only mushroom that forms toothed, woody, perennial fruit bodies.

FISTULINA HEPATICA (Schaeff.) With.

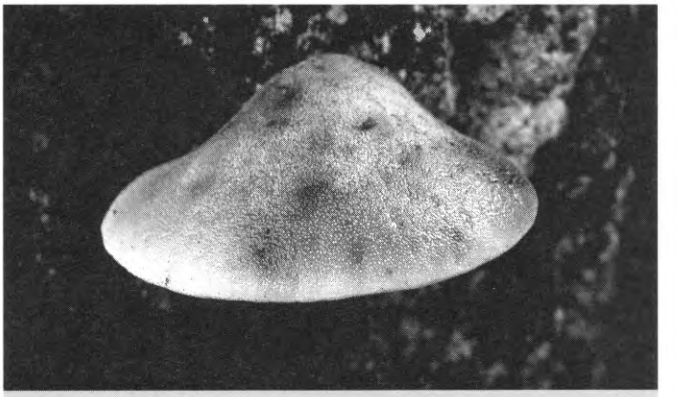
Beefsteak Fungus, Ox Tongue, Poor Man's Beefsteak, The Jelly Tongue

SPORES: 3.5–4.5x2.5–3 µm, smooth, ovoid, inamyloid, pinkish/pinkish-brown. **STALK:** Absent/rudimentary and lateral, cap color, firm. **FRUIT BODY:** 10–30 cm across, irregular, fan-shaped, tongue-like, occasionally fused with other caps, finely bumpy/velvety/smooth, margin lobed, red/reddish-orange/liver-colored. Flesh whitish, streaked with reddish areas, thick, soft, watery, exuding a reddish juice if squeezed, odor indistinct, taste sour/acidic, muscle-like. **TUBES/PORES:** Easy to separate, ≤1.5 cm long, whitish/pale pinkish/reddish-brown, bruising reddish-brown.

RANGE: Eastern North America, Texas, and California, Europe, Australia, North Africa. **ECOLOGY:** Saprobic, sometimes weakly parasitic on bases/stumps of hardwoods (especially oaks/chestnut), causing a brown rot. **GROWTH HABIT:** Solitary/small groups. **SEASON:** Annual, summer–fall.

EDIBILITY: Yes—uniquely fleshy, sweet, sour, citrusy. Rich in vitamin C. Parboiling removes sourness and nutrients. **MEDICINAL:** Anticancer, strong antioxidant, antibacterial. May help gout and gouty arthritis. Has several volatile compounds (essential oils) that contribute to its flavor and scent.

CULTIVATION: Possible indoors, but not common. Fruits from hardwood logs and stumps if 2-inch-deep holes are drilled after mycelium has run through the wood.



N.6 – *Fistulina hepatica* looks like meat, tastes like fruit.

FOMES FOMENTARIUS (L.) Fr.

Amadou, Tinder Conk, Ice Man Fungus, Surgeon's Agaric, Japan: *Tsuriganetake*, India: *Gharikum*, Germany: *Wundschwamm* (Wound Sponge), Italy: *Esporija Pare Heridas* (Sponge for the Wound)

SPORES: 15–20x4.5–7 µm, cylindrical, smooth, white. **STALK:** Absent/rudimentary. **FRUIT BODY:** 5–45x2–25 cm, hoof-shaped/shelf-like, woody, grayish, cracked/furrowed, margin brown/cream, with crust in older species, taste sour/bitter, dark blood red in KOH. **PORES:** 4–5/mm, circular, grayish-brown/cream. Tube layers 2–7 mm long.

RANGE: North America, Europe, Asia, across Africa. **ECOLOGY:** Boreal/temperate woodlands on birch/aspen/willow/alder/maple/beech/cherry/poplar/hickory. Proven to be an endophyte in birch trees, not a parasite. **GROWTH HABIT:** Perennial. **SEASON:** Spring–fall.

MEDICINAL: Diuretic, laxative, steadies nerves, boosts immunity, enhances blood circulation, regulates blood sugar, and lowers blood pressure. Good for hemorrhoids, ingrown toenails, bladder disorders, dysmenorrhea. Used by the Cree to treat frostbite by direct application. Inhibits herpes simplex

virus in vivo. Antiviral, anti-inflammatory, anticancer (throat, stomach, uterus). Styptic function recognized by many cultures. Contains over 10 sesquiterpines (essential oils). **Dyes:** Iron=brown (fresh), dark brown (dried). **Other:** Found on Ötzi. Cherished as a fire source by many cultures, see Chapter 3. Found in campsites from 8000 BCE. Releases 1 trillion spores per season.

Cultivation: Can fruit on birch, maple, beech, and alder sawdust.

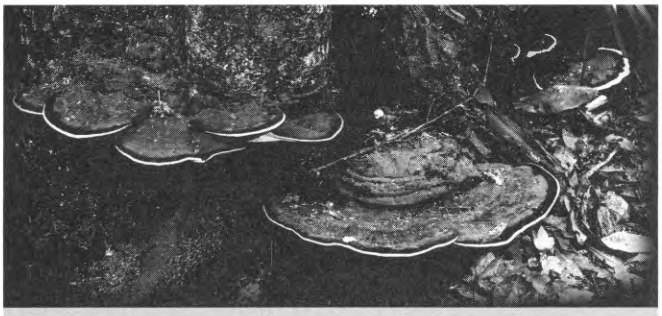
Ganoderma applanatum (Pers.) Pat.

Artist's Conk, Japan: *Kofukisarunokosshikake*, India: *Phanasomba*

Spores: 6–9.5x4.4–7 µm, elliptical/slightly truncate at apex, thick-walled, minutely spiny, brown/reddish. **Stalk:** Absent. **Fruit Body:** 5–75+x2–20 cm, fan-shaped/semicircular, hard crust, ridged/lumpy/knobby, gray-brown/red-brown/grayish-black, often covered by spore powder, flesh corky, no varnished appearance. **Pores:** 4-6/mm, whitish, browning when scratched. Tube layers 4-12+ mm, separated by thin flesh layer.

Range: One of the most common mushrooms in the world. **Ecology:** Only on dead/severely stressed hardwoods/conifers (balsam poplar/spruce/maple/western cedar/bay laurel/oak/magnolia/acacia/eucalyptus/elm/Douglas-fir/beech/alder/apple/buckeye/horse chestnut/walnut/willow), forming a mottled white rot. **Season:** Perennial.

Medicinal: Used as a footbath for gout. Potential for ulcers. Inhibits tumor growth. Stimulates NK cell activity. Antitumor, antiviral, antibacterial, immunomodulating, antidiabetic, antioxidant, and anti-inflammatory. May help eye diseases, lower blood sugar and cholesterol levels, stop pain, eliminate indigestion, and reduce phlegm. Tea may be purgative against parasites and a treatment for bacterial infections. In Traditional Chinese Medicine: reduces mucus, resolves indigestion, treats hemostasis, removes heat, reduces altitude sickness. **Dyes:** No mordant=dull yellow, ammonia=rust color. **Other:** Largest reported fruit body: 311cm x 81cm tall, 52 kg from SE Alaska in 1951. Third largest mushroom in the world. Can be a fire starter. If spore layer does not produce in summer, the mushroom is dead. Can be grown with Turkey Tail on the same stump.



N.7 – *Ganoderma applanatum* conks in their typical shelving form.

N.8 – *G. applanatum* in a tower of growth layers.

Ganoderma tsugae Murrill

Hemlock Varnish Shelf

Spores: 13–15x7.5–8.5 µm, +/- elliptical, sometimes with truncated end, appearing double-walled, with a row of "pillars" between the walls, brown. **Stalk:** 3–14x1–3 cm, absent/present, twisted, equal/irregular, varnished and colored like the cap, lateral. **Fruit Body:** 5–30 cm, irregularly knobby/elongated/fan-shaped, shiny and varnished surface, often with lumpy "zones," red/reddish-brown, margin often bright yellow/white. Flesh whitish, soft/tough. **Tubes/Pores:** 4–6/mm, white/brownish, often bruising brown, circular, tubes 2 cm deep.

Region: Widely distributed in eastern North America, reported in SW U.S. **Ecology:** Parasitic on living conifers (eastern hemlock), saprobic on conifer deadwood, producing a white butt rot of the heartwood. **Season:** Annual, fall.

Edibility: Too woody to eat. **Medicinal:** Researched, but not as renowned as the better-known *G. lucidum*. Antitumor, promotes wound healing in mice, antioxidant. **Other:** Similar to *G. lucidum* but with white flesh, not brown.

Cultivation: Does well on hemlock stumps.

Ganoderma lucidum (Curtis) P. Karst.

Panacea Polypore, Japan: *Reishi* (Divine/Spiritual Mushroom), *Mannentake* (10,000-Year Mushroom), China: *Ling Chi/Zhi* (Tree of Life Mushroom)

Spores: 7–13x5–8 µm, elliptical, double-walled, minutely roughened, brown. **Stalk:** 3–14x0.5–4 cm, attached laterally/vertical and well developed, often gnarled/twisted, equal/enlarged below, dark red/reddish-black, shiny like cap, sometimes absent. **Fruit Body:** 2–35x4–8 cm, circular/semicircular/fan shape, surface with shiny crust that is smooth/concentrically zoned and grooved. Dark red/reddish-brown/orange-brown/reddish-black, ochre/yellowish toward margin,

margin whitish when growing, surface usually covered with brownish spore powder. Flesh brown/dark brown/pallid near the cap. **Pores:** 4–7/mm, whitish/yellowish-white when fresh, brown in age. Tubes 2–21 mm long, one/two layers, soft and corky fresh, tough when dry/old.

Range: USA (New England to Florida, Midwest to Texas, Pacific NW, California), Amazon, East Asia. **Ecology:** Stump/soil interface and off roots of eastern hemlock/spruce/pine/maple/oak/alder/elm/willow/sweetgum/magnolia/locust/plum. **Growth Habit:** Annual **Season:** May–Nov. May overwinter.

Edibility: Tough and bitter. Best as tea/extract. **Medicinal:** Heavily researched, highly revered. The Chinese once believed a tincture on the chest of the dead could bring them back to life. See Chapter 7 for a taste of its vast medicinal potency. **Dyes:** Ammonia=warm golden beige/rust.

Cultivation: Good strains will fruit in the bag and can be left to form antlers with no need for humidification. Alternately, once desired stalk length is achieved, open bag and shelf will form atop stalk. Bottle culture on its side requires less humidity control and is common is Asia. Conks form from sides of perforated bags. Excellent on stumps, buried logs (mycotems), and raft style beds.

Sawdust – 78%
Wheat bran – 20%
Gypsum – 1%
Soybean powder – 1%

Bagasse – 75%
Wheat bran – 22%
Cane sugar – 1%
Gypsum – 1%
Soybean powder – 1%

Cotton seed hull – 88%
Wheat bran – 10%
Cane sugar – 1%
Gypsum – 1%

Sawdust – 70%
Corn cob powder – 14%
Wheat bran – 14%
Gypsum – 1%
Cereal straw ash – 1%

Corn cob powder – 78%
Wheat/rice bran – 20%
Gypsum – 1%
Straw ash – 1%

Gloeophyllum sepiarium (Wulfen) P. Karst.

Rusty Gilled Polypore

Spores: 9–13x3–5 µm, smooth, cylindrical, inamyloid, hyaline in KOH, white. **Stalk:** Absent. **Fruit Body:** ≤12x8 cm, semicircular/irregularly bracket-shaped/kidney-shaped, flattened-convex, velvety/hairy, rugged, with concentric zones, yellow/orange/yellow-brown/dark brown/black, margin usually remaining yellow/orange. Flesh dark rusty-brown/dark yellow-brown and corky, turns black to KOH. **Pores:** Gill-like in appearance, irregular, often fusing, close, edges yellow-brown/darker brown, faces creamy/pale brownish, ≤1 cm deep.

Range: North America, Europe. **Ecology:** Saprobic on conifers, occasionally hardwoods, brown rotter in heartwood and sapwood. **Growth Habit:** Single/compound/in groups/overlapping tiers. **Season:** Annual/perennial, late summer–fall.

Edibility: Inedible. **Medicinal:** Anticancer, slightly antifungal, spicy odor caused by various essential oils.

N.9 – The gill-like pores of *Gloeophyllum sepiarium*.

Grifola frondosa (Dicks.) Gray

Maitake (Japanese for "dancing mushroom"), Hen of the Woods, Sheep's Head, Ram's Head

Spores: 5–7x3.5–5 µm, broadly elliptical, smooth, white. **Stalk:** Branching/layered, smooth, fleshy but tough, white/pale grayish, off center/laterally attached to sides of caps. **Cap:** 2–10 cm broad, spoon/tongue/fan-shaped and flattened, dry, smooth/rough/fibrillose, gray/brown/grayish-brown, margin usually wavy. Flesh white, firm, tough; taste mild when young. **Pores:** 1–3/mm, white/yellowish. Tubes 2–3mm long, decurrent.

Range: Northern temperate deciduous forests in North America, East Canada, NE Japan, China, Europe. **Ecology:** The base of old trees/stumps, primarily oak, but also chestnut/elm/maple/blackgum/beech/larch. Forming a white butt and root rot. **Season:** Perennial, late summer–early fall.

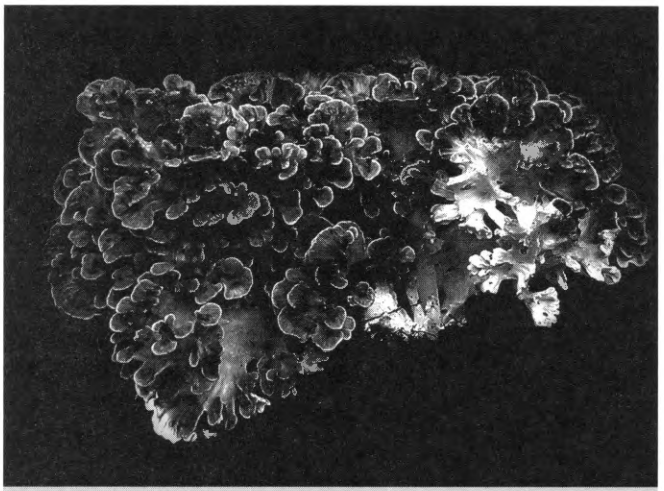
Edibility: Choice—27% protein, vit. B1, B2, niacin, C, D, iron, calcium, phosphorus. **Medicinal:** Well researched, highly regarded. See Chapter 7 for details. **Remediation:** PCBs. **Dyes:** Ammonia=soft yellow.

Cultivation: Slower growing. Tricky to fruit indoors. Prefers to be close to the ground when fruiting. ≤15% bran recommended, addition of humus-rich soil helps. Best method outdoors is to inoculate oak stumps/roots or large rounds that are then buried just below the soil horizon.

Hardwood sawdust (3 parts fine: 1 part coarse) – 75%
Wheat bran, not refined – 23%
Sucrose – 1%
Lime and/or gypsum – 1%
Moisture content – 60-63%
pH 5.5–6.5

Hardwood sawdust (3 parts fine: 1 part coarse) – 80%
Wheat bran, coarse – 18%
Lime – 1%
Sucrose – 1%
Soil, hardwood forest (surface), dry wt. 15% (of the above mixture)
Moisture content – 60-63%
pH 5.5–6.5

Hardwood sawdust (fine 40%, coarse 20%)
Spent sawdust substrate – 20% dry weight
Wheat bran (coarse) – 10 %
Hardwood forest soil – 10% dry weight
Moisture content – 60–63%
pH 5.5-6.5



N.10 – *Grifola frondosa*, in its exquisite and delicious wild form.

Hericium erinaceus (Bull.) Pers.

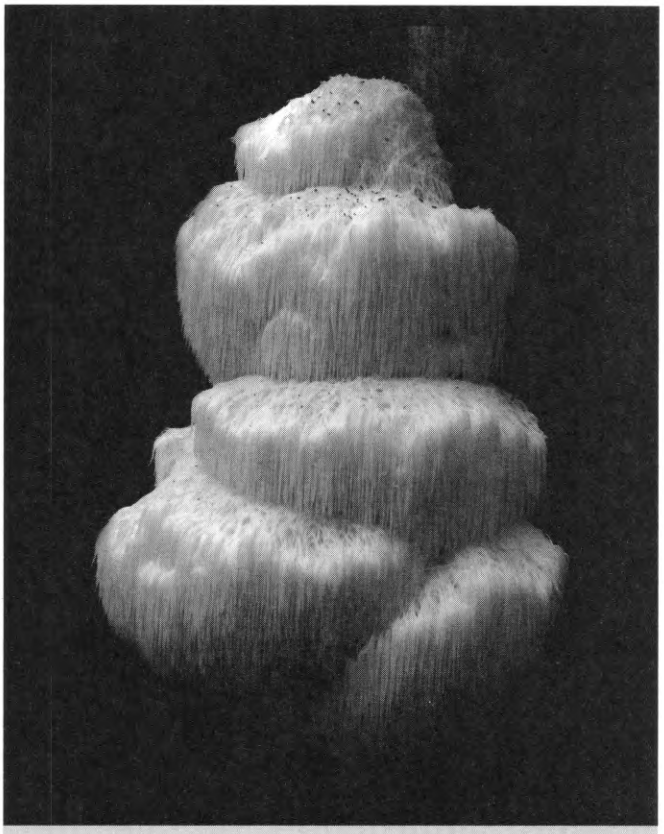
Lion's Mane, Monkey's Head, Sheep's Head, Bear's Head, Old Man's Beard, Satyr's beard, Pom Pom, Houtou

Spores: 4–5.5x5–6.5 µm, elliptical/subglobose, amyloid, smooth/minutely roughened, white. **Fruit Body:** 8–40 cm across, unbranched, white/yellowish. Flesh white, not bruising when cut. **Teeth:** 1–6 cm, soft, white/yellowish.

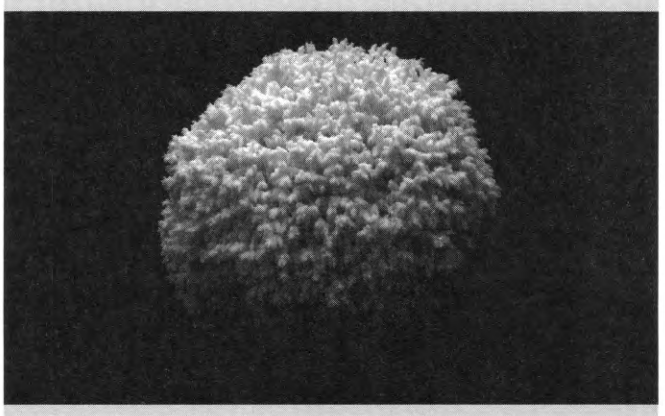
Range: North America, Europe, Japan, China. **Ecology:** Saprobic and parasitic white rotter on hardwoods (oak/walnut/beech/maple/sycamore logs/stumps). **Growth Habit:** A single clump of dangling spines. **Season:** Summer–fall.

Edibility: Delicious—taste and texture of crab. 31% protein, 17.6% carbs, sodium, phosphorus, iron, calcium, potassium, magnesium, thiamin, riboflavin, calciferol, niacin. **Medicinal:** Produces erinacines and hericiones: strong nerve growth factor stimulators. Helps rebuild myelin, increase cognitive ability, repair neurological trauma/degeneration, and may mitigate Alzheimer's and Parkinson's. Anticancer (gastric, stomach, liver), antibacterial, anti-*Candida*, anti-inflammatory.

Cultivation: Slow on agar, forming neural-like pattern. LC is preferred inoculum. Mycelium not strong. Readily fruits on grains. Often hearty once established on nutrified sawdust (maple/oak/beech/elm/walnut/sycamore)—keeps popping out fruit bodies every few weeks. Does well on mycotems (partially buried logs). The related *H. americanum* grows similarly but is branched. *H. abietis* grows on conifer wood.



N.11 – *Hericium erinaceus* in a glacier-like cascade.



N.12 – *H. coralloides*, a close relative of *H. erinaceus*, is also edible.

HETEROBASIDION ANNOSUM (Fr.) Bref.

Conifer Base Polypore, Annosum Root Rot

SPORES: 3.5–5x3–4 µm, elliptical/round, minutely spiny, white. **FRUIT BODY:** 2.5–45 cm wide, flat, with wavy margin, whiteish/gray-brown/dark brown/reddish/blackish, hairy/smooth, usually zoned/furrowed concentrically. Flesh 0.2–1 cm thick, white/pinkish, hard, with thin, black, crust-like skin, no distinct odor/flavor. **PORES:** 2–5/mm, indistinctly layered, circular/angular/deformed, white/yellowish, tubes 2–10 mm long.

ECOLOGY: Parasitic on conifers/hardwoods/timber, causing butt rot. **GROWTH HABIT:** Singular/several, projecting from spreading, crust-like mass, occasionally fused in rows. **SEASON:** Perennial, grows summer–fall.

EDIBILITY: Too woody to eat. **MEDICINAL:** Scandinavian cancer treatment. Antibacterial, anticancer. Used for pain. **OTHER:** Commonly confused for *Fomitopsis pinicola*. May be a complex of many species.

N.13 – *Heterobasidion annosum.*

INONOTUS OBLIQUUS (Ach. ex Pers.) Pilát

Chaga, Clinker Polypore, Japanese: *Kabanoanatake,* Norway: *Kreftjulce,* Finland: *Tikkatee,* Woodpecker Tea, Cree: *Posahkan,* Gitksan (B.C.): *didihuxw*

SPORES: 7.5–10x5–7.7 µm, broadly elliptical, smooth, white/light yellow. **FRUIT BODY:** ≤5mm thick, crust-like, thin, dark brown, rarely encountered. **PORES:** 3–5/mm, white/dark brown. Tubes 5–10 mm long, oblique, split, angular/elongate. **SCLEROTIA:** 25–40 cm wide, black, hard, deeply cracked, gnarled, irregular, deep red interior.

RANGE: Circumpolar. Throughout boreal deciduous forests of North America, Eastern and Northern Europe, Canada, Russia, Korea. Forms a white heart rot on living birch. **ECOLOGY:** Primarily birch, also elm/alder. **SEASON:** Late spring–early fall.

MEDICINAL: Highly valued in many parts of the world. In Siberia: for liver ailments, worms, stomach problems, tuberculosis, and as a blood tonic and purifier, pain reliever. Inhibits oxidative stress, stomach ulcers, diabetes, psoriasis. Anti-inflammatory, antiviral (HIV, influenza), immune stimulant, anticancer (gastric, breast, lung, uterine liver), black surface is antiviral, strong antioxidant. Increases bioelectric activity in the brain's cortex. An array of medicinally active compounds have been isolated. An anticancer drug in Russia. High in essential oil compounds. Decoction: 1 Tbsp./3 L. Soak for 4 hours, strain, add 50°C water to marc and let sit at room temp for 2 days. Add 2 parts to 1 part ETOH extract. **OTHER:** Paste made from sclerotia and water can be placed in blight lesions to heal trees. See Chapter 3 for various other applications.

CULTIVATION: Naturalized methods preferred on dying/dead birch trees/stumps/logs.

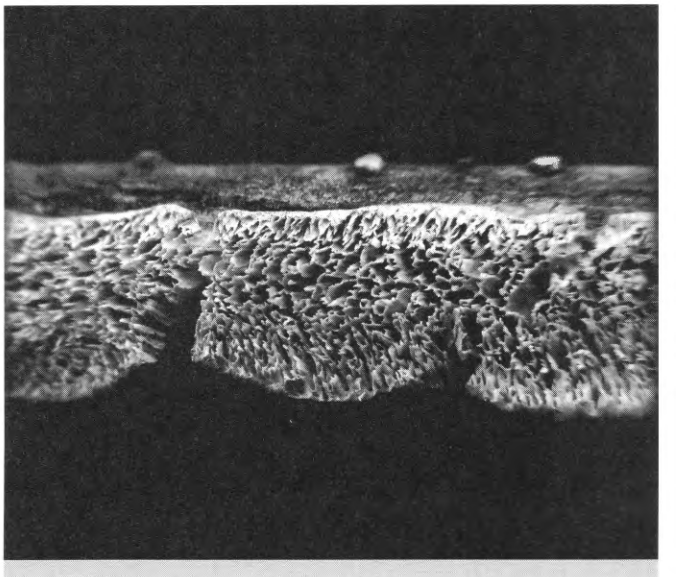
IRPEX LACTEUS (Fr.) Fr.

White Rot Fungus, Milk-White Toothed Polypore

SPORES: 50–110x5–10 µm. **STALK:** Absent. **FRUIT BODY:** 1–4 cm wide, kidney-shaped/irregular, whitish/grayish, often zoned, velvety/hairy, flesh thin, whitish, and tough, all parts brownish-orange in KOH. **PORES:** 2–3/mm. Tubes 1–5 mm long, breaking into flat teeth.

RANGE: North America. **ECOLOGY:** Conifers/deciduous dead wood, live cherry trees. **GROWTH HABIT:** Commonly overlapping/fused, projecting from spreading mass. **SEASON:** Year-round, annual.

MEDICINAL: Antibacterial, anticancer, anti-inflammatory. **REMEDIATION:** Well researched. Known to degrade a range of aromatic compounds.



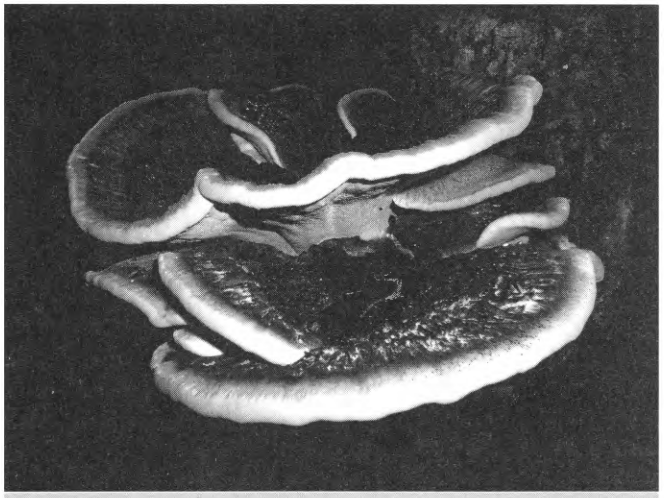
N.14 – *Irpex lacteus* bears spores in teeth-like pores.

ISCHNODERMA RESINOSUM (Schrad.) P. Karst
Resinous Polypore, Benzoin Bracket

SPORES: 4–7x1.5–2.5 µm, sausage-shaped/cylindrical, smooth, white. **STALK:** Absent. **FRUIT BODY:** 5–30x1–3 cm, kidney-shaped/semicircular, surface like sandpaper/smooth/wrinkled/resinous, may be concentrically zoned/ridged, dark brown/blackish. Flesh whitish/beige/tan/brownish, watery/tough/corky, thick margin, often exuding droplets, anise-like odor, all parts grayish/blackish with KOH. **PORES:** 3–6/mm, creamy/ochre/brownish. Tubes 1–10 mm long.

RANGE: North America, Africa, Asia, Europe. **ECOLOGY:** On dead hardwood/conifer. **GROWTH HABIT:** Solitary/several, overlapping. **SEASON:** Summer–fall.

EDIBILITY: Edible when young. **MEDICINAL:** Anticancer, antimicrobial.



N.15 – *Ischnoderma resinosum.*

LAETIPORUS SULPHUREUS (Bull.) Murrill *& ALLIES*
Chicken of the Woods, Sulfur Shelf

SPORES: 5.5-7x3.5-5 µm, smooth, elliptical/ovoid, inamyloid, white. **STALK:** Absent. **FRUIT BODY:** 5–30 cm across and up to 20 cm deep; up to 3 cm thick; fan-shaped/semicircular/irregular, smooth/finely wrinkled, suede-like, bright yellow/bright orange, fading in maturity and sunlight. Flesh thick, soft and watery/tough/crumbling, white/pale yellow. **PORES:** 2–4/mm, circular/angular, yellow. Tubes ≤5 mm.

RANGE: North America, Europe, Mediterranean region (carob/eucalyptus). **ECOLOGY:** Parasitic and saprobic on living and dead oaks/plums/fruit/poplar/willow/beech/conifers, causing a reddish-brown cubical heart rot. **GROWTH HABIT:** Several/many individual caps in a shelving formation/rosette. Usually reappearing annually. **SEASON:** Sept.–Oct.

EDIBILITY: Good—chicken-like texture, taste like crab or lobster. Should not be eaten raw. If grown on conifer, can cause GI distress in some people. **MEDICINAL:** Inhibits staph and the microbe responsible for UTIs and tropical infections. Good for cystic fibrosis, cuts, burns. **REMEDIATION:** Surprisingly grows on telephone poles, but is not well researched. **OTHER:** Long considered one species. Genetic sequencing reveals 6 North American species, each with distinct niches. A "fool-proof" mushroom, with no close look-alikes (other than its siblings).

CULTIVATION: Mycelium fragrant. Studies from Poland have demonstrated indoor fruiting. Mycelium is so light and weak that it can't hold up a shelf forming from the side of a bag—a crutch is needed. Best on logs/stumps/snags.

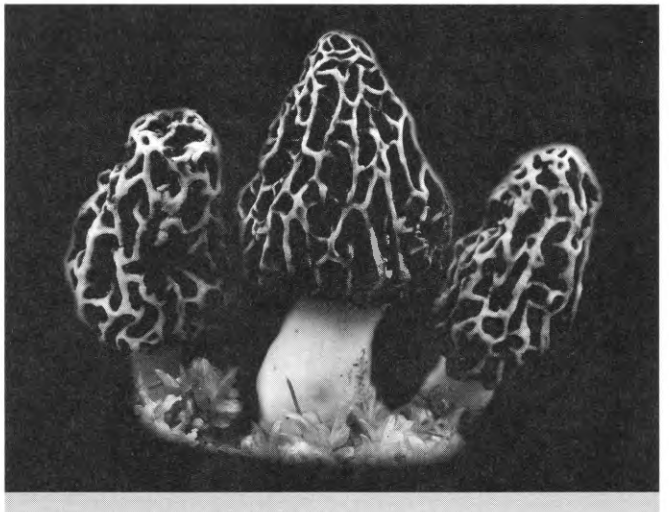
N.16 – *Laetiporus* species share a common form and color.

MORCHELLA ANGUSTICEPS Peck *& ALLIES*
Morel, Black Morel

SPORES: 22–27x11–15 µm, smooth, long-elliptical, no oil droplets, 8 spores/ascus. **STALK:** 2–8x1–3 cm, equal/with slightly swollen base, whitish/pale brownish, finely mealy/nearly bald, sometimes with folds, hollow. **CAP:** 3–8x2–5 cm, usually conical/bluntly conical, with a sharp/bluntly/egg-shaped apex, nearly bald/finely velvety, flattened, tan/brown/dark brown/black ridges and dull brownish-yellow/olive pits, attached to stem with a 2–5 mm deep groove, hollow.

RANGE: North America, Europe, Asia, Himalayas, widely distributed. **ECOLOGY:** Unusual. Seemingly saprobic or mycorrhizal, depending on life cycle stage. Often in burned areas/old apple orchards/under hardwoods (white ash/green ash/elms/spens/balsam/poplar/sycamores/tulip/conifers/pine/apple). **GROWTH HABIT:** Solitary/scattered/in groups. **SEASON:** Short spring window varies by region. March–May. In the Cascades when calypso orchids are blooming.

Edibility: Choice—umami-rich. 20% protein, 4.8% fat, 8.7% fiber, 64.4% carbs. Breathing the fumes of cooking morels can be dangerous, perhaps deadly. **Medicinal:** Helps with reducing phlegm, regulating vital energy flow in the body, indigestion, excessive sputum, shortness of breath. **Remediation:** Accumulates lead (70–100x) and arsenic (especially in old apple orchards). **Cultivation:** Incredibly fast growing mycelium. Complex life cycle has produced limited success with consistent fruitings. Needs a cold period and passage through a nutrient-poor zone. Produces edible sclerotia on grains. The best option is to expand a local strain and inoculate various disturbed/burned areas with spawn, gypsum, and ashes.



N.17 – *Morchella prava*, a close relative to *M. angusticeps*.

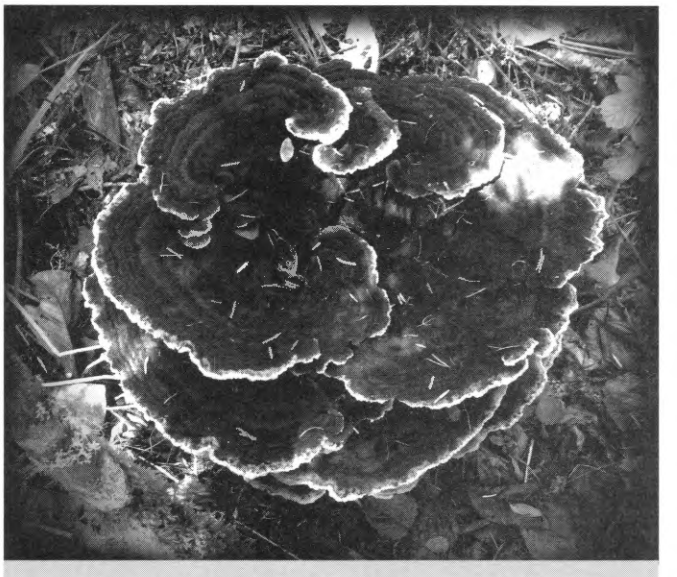
Phaeolus schweinitzii (Fr.) Pat.

Dyer's Polypore, Velvet Top, Dyer's Mazegill

Spores: 5–9x2.5–5 µm, elliptical, smooth, white/yellowish. **Stalk:** If present, 1–6 mm long and 1–5 cm thick, tapered down, rooting, central/off center, color and texture like cap. **Fruit Body:** 5–30+ cm, circular/fan-shaped/plane/depressed, soft and spongy/tough and corky, brittle, dry, surface with mat of woolly hairs/smooth, orange/ochre/yellowish/greenish-yellow/rusty brown/dark brown, bruising brown/blackish, occasionally zoned with concentric colors, margin wavy, flesh yellowish/rusty-brown. KOH black on surface. **Pores:** 1–3/mm or fused forming larger pores, mustard/greenish/brown/blackish. Tubes 2–10 mm long, usually decurrent.

Range: Throughout western U.S., Europe, Asia, New Zealand, Australia, South Africa. **Ecology:** On dead/living conifer stumps/roots (fir/spruce/hemlock/pine/larch). **Growth Habit:** Solitary/in groups, compound, composed of several tiered caps arising from shared base, sometimes with one cap/growing shelf-like on wood. **Season:** Summer–fall.

Edibility: Considered poisonous. **Medicinal:** Contains a stimulant found in the roots of the kava-kava plant. Antimicrobial, anticancer, antibacterial. **Dyes:** Ammonia=orange, ammonia + copperpot=deep green, ammonia + iron pot=red rust, salt water=bright yellow, iron mordant=burnt sienna (fresh) or dark brown (dried).



N.18 – *Phaeolus schweinitzii*, the classic mushroom for dyeing fabrics.

Phallus impudicus L.

Stink Horn, India: *Jhirri Pihiri*, Germany: *Stink-Morchel*

Spores: 3–5x1.5–2.5 µ, elliptical/oblong, smooth, olive-green/olive-brown. **Stalk:** 1.5–3x 2–6 cm, equal/tapered at both ends, entirely white/pinkish below, minutely honeycombed, hollow, fragile. **Top:** 1.5–4 cm, coated with the foul smelling spore slime that drips off, whitish and reticulate tissue underneath, top with a hole. **Veil:** Absent/rudimentary, volva at base.

Range: North America, Europe, Canada, Asia, Taiwan, India Costa Rica, Iceland, Tanzania, Australia. **Ecology:** Humus-rich ground/gardens/near conifers/mainly beneath broadleaf. **Season:** Spring–late fall.

Edibility: Radish-like taste. Egg stage with multiple layers of strange textures. **Medicinal:** Cooked with cherries to relieve gout. Used for sore limbs, epilepsy, ovarian cysts, uterine fibroids, cancer (breast, uterus, ovarian). In India: crushed in water (1 tsp., 3x/day) for labor pains. Anti-inflammatory, anti-stress. Extends the life expectancy of mice. Enhances immune system. In Traditional Chinese Medicine: rheumatism. Rogers suggests extracts of 1:2 in 25% ETOH, 20–40 drops/day or 9–15 grams powder, 3x/day. In homeopathy: prevents blindness and eye disease, color-blindness, 6C taken internally and as eye drops. **Other:** Erection takes place at night, completed by dawn. Smell caused by hydrogen sulfide. Produces non-luminous light that penetrates cardboard and picks up on photographic plates. Used in Nigeria to make hunters invisible.

PHELLINUS IGNIARIUS L.

False Tinder Conk, Punk Ash, Flecked-Flesh Polypore, Willow Bracket, Fire Sponge, Yup'ik: *Araq*

SPORES: 5–7 x4–6 µm, round, smooth, whitish. **STALK:** Absent/rudimentary. **FRUIT BODY:** 5–20+x2–20 cm, shelflike/bracketlike/hoof-shaped, surface usually with a crust in older specimens, velvety/bald, brown/gray/black, cracked, furrowed, margin brown, taste sour/bitter. Flesh hard, woody, rusty-brown/brown. **PORES:** 4–5/mm, grayish-brown/brown, tube layers 2–5 mm long.

RANGE: Northern half of North America. **ECOLOGY:** On hardwood trunks (willow/birch/alder/poplar/aspen/madrone/Manzanita/maple). **GROWTH HABIT:** Solitary/in groups. **SEASON:** Perennial.

EDIBILITY: Too woody to eat. **MEDICINAL:** Artic tribes boil and drink as a laxative and for stomachache. Anticancer (lung, prostate, stomach), invigorates blood circulation, immune regulator, antioxidant. Used for treatment of urinary tract, diarrhea, and stomach pains. Mycelium best extracted at 70°C (158°F) for 90 min. (1 part mushroom to 6.2 parts water).

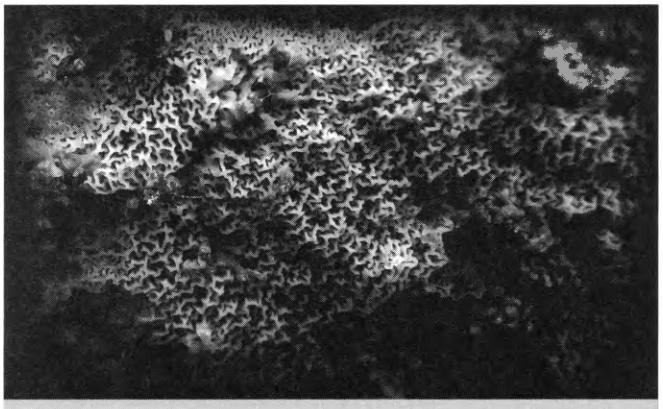
PHLEBIA TREMELLOSA

(Schrad.) Nakasone & Burds.

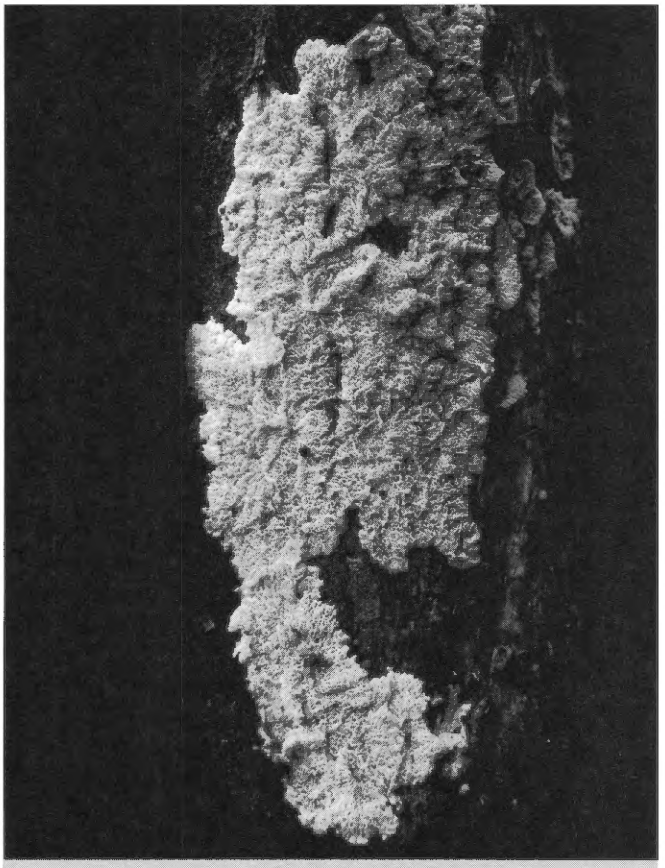
SPORES: 3.5–4.5x1–2 µm, smooth, sausage-shaped, inamyloid. **STALK:** Absent. **FRUIT BODY:** 3–10 cm across, 5 mm thick, translucent, softish, elastic, gelatinous, orangeish/pinkish/red, wrinkled/pocketed, appearing poroid, upper surface woolly and whitish. Flesh white, thin.

RANGE: Widespread in North America. **ECOLOGY:** On dead hardwoods/conifers. **GROWTH HABIT:** Overlapping clusters, resupinate except for a stubby upper edge. **SEASON:** Summer–fall.

EDIBILITY: Inedible. **MEDICINAL:** Anticancer, antibacterial, antifungal. **REMEDIATION:** Highly effective against chlorinated pollutants. Potential for textile and pulp mill wastes.



N.19 – The folds of *Phlebia tremellosa*.



N.20 – *Phlebia tremellosa* sheathing a tree.

PIPTOPORUS BETULINUS (Bull.) P. Karst.

Birch Polypore, Birch Bracket, Razor Strop, Japan: *Kanbatake*

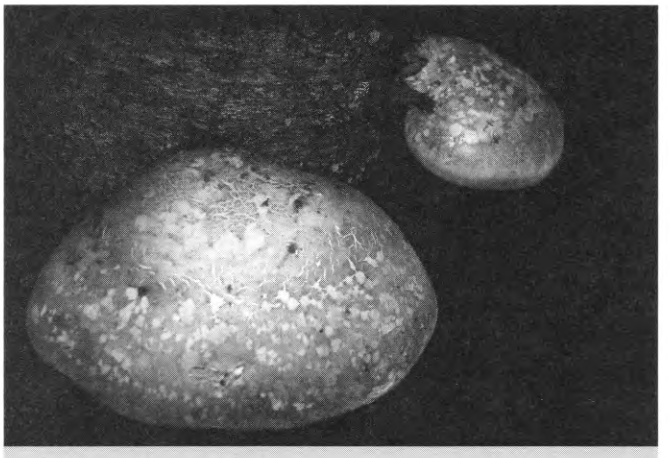
SPORES: 3–6 x 1.5–2 µm, cylindrical to sausage-shaped, smooth, white. **STALK:** Absent or only as a short cap extension of the cap, lateral/attached to cap's top. **FRUIT BODY:** 5–25x2–10 cm, outline kidney-shaped/round, convex/plane, surface smooth/suede-like, white/buff/tan/brown/grayish-brown, may have crust broken into scales, margin blunt, thick, inrolled. Flesh rubbery/corky, thick, and white. **PORES:** 2–4/mm, recessed due to thick margin, white/pale brown/grayish-brown, torn/tooth-like. Tubes 2–10 mm long in a single layer.

RANGE: North America, Canada, Europe. **ECOLOGY:** Temperate birch forests. Primarily on birch, occasionally beech. Forming a cubical brown rot. **GROWTH HABIT:** Solitary/in groups/columns on dead/living birch trees. **SEASON:** Grows summer–fall.

EDIBILITY: Yes—when young and fresh, but with a bitter taste. **MEDICINAL:** Immune boosting, anti-inflammatory, styptic, reduces fatigue, soothes the mind, effective against intestinal parasites due to toxic oils. Concentrates the anticancer compounds betulinic acid and betulin from birch

bark. Antiviral (HIV), antifungal. antitumor. Polyporenic acid is anti-inflammatory. Piptamine is antibiotic. Contains sugars chemically similar to schizophyllan. Rich in essential oils. In homeopathy: antiviral, immune tonic, chi regulator. **Remediation:** Produces some of the highest levels of cellulase. **Other:** Smoke is calming to bees. A razor strop, anaesthetic, sharp tool holder, silver polisher, and tinder source. Found with Ötzi.

Cultivation: Mycelium in LC takes on a unique, ropey appearance. Best on birch, though alder, spruce, poplar, and pine have been successful.



N.21 – *Piptoporus betulinus.*

Pisolithus tinctorius (Mont.) E. Fisch.

Dead Man's Foot, Dye-Maker's False Puffball, Horse Dung Fungus, Japan: *Kotsubutake*

Spores: 7–12 µm, round, warty/spiny, dark brown. **Fruit Body:** 5–30+ cm high, 4–20 cm broad, round/pear/club-shaped, sometimes with narrowed, rooting base/stalk, breaking up in age, odor mild/aromatic/unpleasant, thin, brittle, yellowish/purplish/olive-black/brown, lustrous, ruptures irregularly, containing hundreds of disintegrating and seed-like peridioles, eventually crumbly/dusty. **Peridioles:** 2–4 mm, elongated/oval/circular, whitish/greenish-yellow/yellow/brownish/deep red, in sticky dark substance/dry and brittle. Volva absent.

Range: Worldwide, North America, Europe, Asia, Australia. **Ecology:** Acidic, thin, sandy soils, pinelands, dunes, grasslands. Associated with a wide range of trees/shrubs (oak/pine/juniper). **Season:** July–Oct.

Edibility: Not recommended. In Europe it is known as the "Bohemian Truffle" used for aromatic seasoning. **Medicinal:** Anticancer (leukemia, melanoma). Rogers suggests 6 mg dissolved in water with sugar 2x/day. In Traditional Chinese Medicine: relieves swelling, stops running pus, staunches esophageal and stomach bleeding. **Remediation:** A versatile ectomycorrhizal fungus. Associated with many trees, a good companion in poor soil silviculture. Tolerant of high heat and heavy metals. **Dye:** No mordant=deep red-brown/black (fresh), golden brown (old/dry). Alum+iron=nice chocolate brown. Also gold, yellow, dark blue, and black.

N.22 – *Pisolithus tinctorius* is filled with spore-bearing peridioles.

Podaxis pistillaris (L.) Fr.

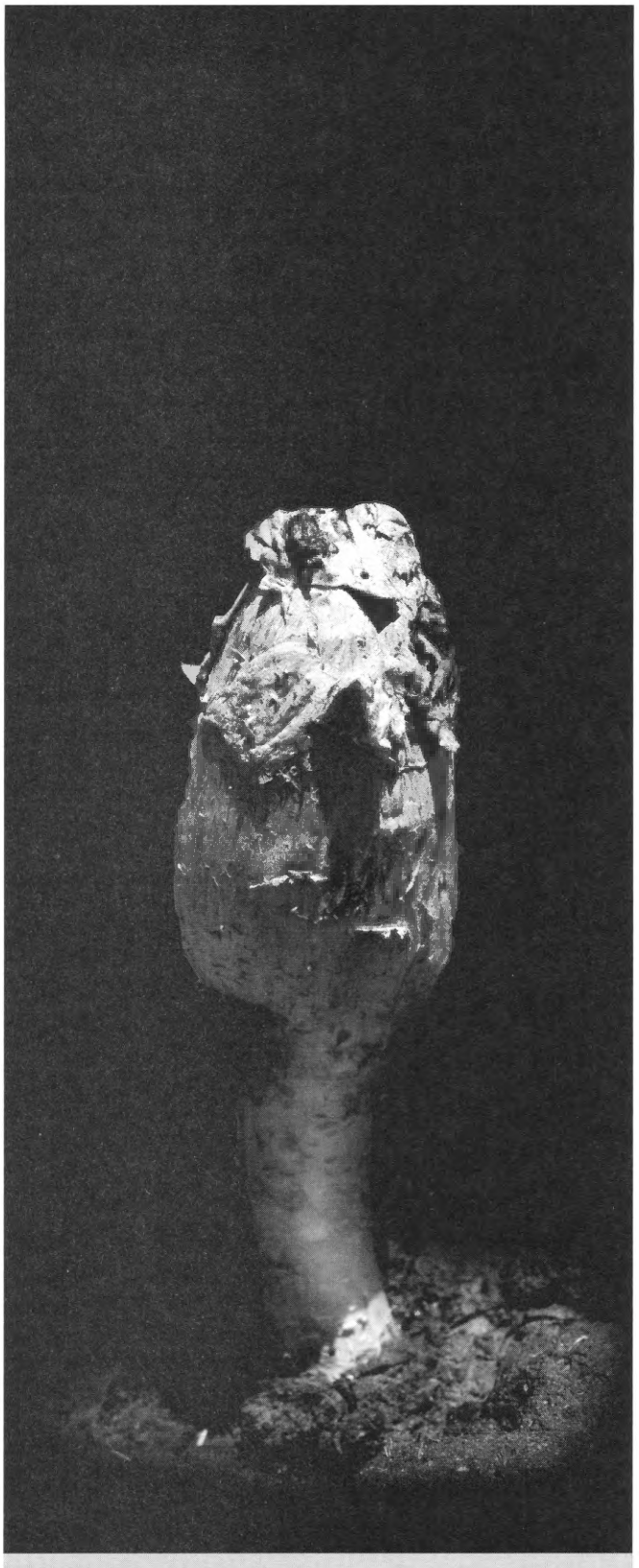
Desert Shaggy Mane

Spore Features: 10–20x9–15 µm, broad/broadly elliptical, pear-shaped/irregular, smooth, thick-walled, with apical germ pore, yellow/deep reddish-brown. **Stalk:** 4–26x0.2–1.5 cm, equal with swollen base, long and slender, tough and fibrillose/scaly, solid/hollow, twisted-striate, white/discolored, volva absent. **Cap:** 2–15x1–4 cm, oval/cylindrical/twisted, surface dry pure white/tan/yellow-brown/brown, typically breaking up into shaggy scales that reveal a smooth undersurface, containing a spore mass of contorted/rudimentary gills that are white/yellowish/reddish/reddish-brown/dark brown/blackish, powdery at maturity.

Range: North America, India, Hawaii, Australia. **Ecology:** Deserts/washes/lawns/gardens/fields. **Growth Habit:** Solitary/scattered/gregarious/clustered on ground. **Season:** Spring–fall.

Edibility: Edible when young. Others say inedible to fibrous and woody, 21% protein.

Cultivation: Research at Sindh Agriculture University (Tandojam, Pakistan) has shown that *P. pistillaris* spores can be spread on sandy/sandy-loam soil (directly on the ground or in 9-inch [23 cm] trays) to obtain yields within 30 days.



N.23 – *Podaxis pistillaris*, a desert mushroom that can be cultivated.

POLYPORUS UMBELLATUS (Pers.) Fr.

Lumpy Bracket, Umbrella Polypore, Zhu Ling

SPORES: 8–10x2.5–3.5 µm, cylindrical, smooth, colorless, white. **STALK:** 2.5–7.5x2–3 cm, strongly branched above ground, rising from dark sclerotia. **CAP:** 1–4 cm broad, circular, white/grayish, dry, smooth/fibrous, KOH negative. **PORES:** 2–4/mm, angular, whitish/yellowish. Tubes 1–2mm long, slightly decurrent.

RANGE: Eastern Canada, Tennessee, Ohio, Iowa, Idaho, Washington, Asia. **ECOLOGY:** On ground on buried wood, around stumps or deciduous trees (ash/hickory/beech/willow/maple/spruce/oak). **GROWTH HABIT:** In clusters 3–20 inches (7–51 cm) wide. **SEASON:** May–Oct.

EDIBILITY: Choice. Contains lean proteins and low amounts of cholesterol. Said to help with weight loss. **MEDICINAL:** Potent anticancer properties (especially leukemia, liver, lung), water extracts inhibit malaria, antibacterial, anti-inflammatory, antitumor, antiviral, immune enhancer, liver tonic, lung/respiratory tonic. Helps with edema, barysomatia, hemorrhoids, lowering cholesterol, regulating blood sugar and pressure, improving skin structure, enhancing immune system, preventing infection, enhancing cardiac function. Can increase insulin sensitivity while reducing insulin resistance. **OTHER:** Least expensive of imported medicinal fungi. Despite being a polypore, fruit body is soft enough to eat.

CULTIVATION: A secondary saprobe, it does well on spent substrates (e.g. from Reishi and Shiitake). Place spawn/sclerotia near the roots of beech/birch/willow/oak stumps.

N.24 – *Polyporus umbellatus.*

PSEUDOHYDNUM GELATINOSUM

(Scop.) P. Karst.

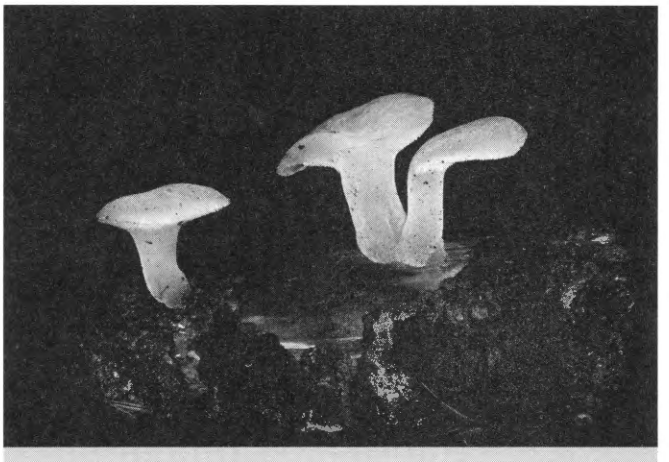
Toothed Jelly Fungus, Cat's Tongue, False Hedgehog

SPORES: 4.5–8 µm, roundish, smooth, white. **STALK:** ≤6 cm long, lateral and stubby/well developed and vertical, gelatinous, smooth, colored like the cap/paler. **CAP:** 1–7 cm across, tongue/

kidney-shaped, broadly convex/flat, gelatinous, not slimy, smooth/finely fuzzy, translucent white/grayish/brown/fairly dark brown. **Teeth:** ≤3 mm, decurrent, translucent white/pale grayish/faintly bluish. Flesh translucent and gelatinous.

Range: Asia, Australia, New Zealand, Europe, North America, Central America, South America. **Ecology:** Saprobic on logs/twigs/humus under conifers. **Growth Habit:** Alone/scattered/gregariously scattered. **Season:** Late summer–winter in warmer climates.

Edibility: Edible. Can be candied. **Medicinal:** Anticancer properties. **Other:** A cute, strange little gem from the forest floor. Only species in the genus.



N.25 – *Pseudohydnum gelatinosum.*

Schizophyllum commune Fr.

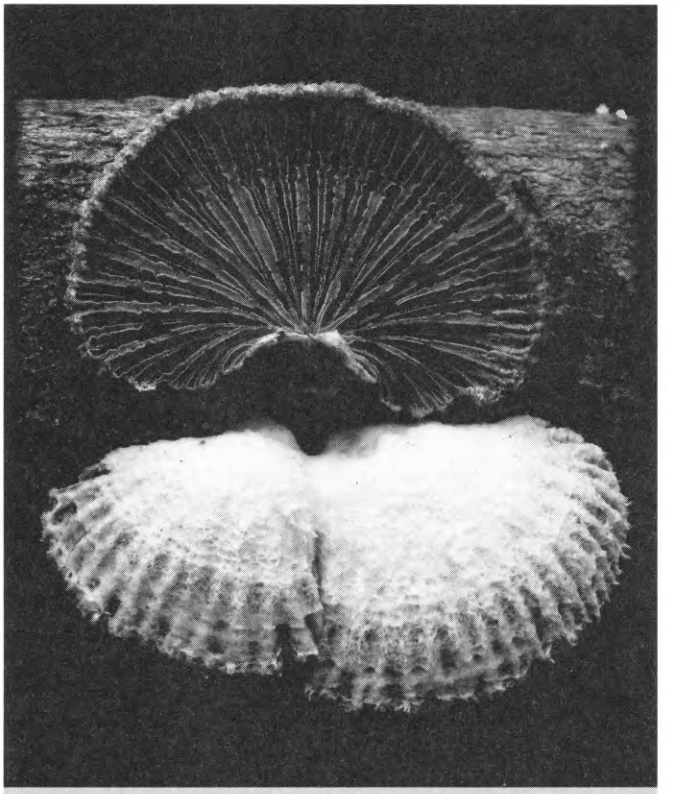
Split Gill, Japan: *Suehirotake*

Spores: 3–6x1–3 µm, white, cylindrical, smooth. **Stalk:** Absent/rudimentary. **Fruit Body:** 1–4 cm broad, shelf-like/with narrowed base, leathery, fan-/vase-shaped, dry, hairy, white/grayish-white/brownish-gray, margin lobed. **Gills:** Radiating from attachment point, widely spaced, white/grayish, edge split/grooved lengthwise, rolling under in dry weather.

Range: Worldwide. **Ecology:** On sticks/stumps/logs (poplar/birch/pine/conifers/hickory). **Growth Habit:** Scattered/in groups/rows/fused clusters. **Season:** Year-round.

Edibility: In Zaire: boiled for hours with salt, then served with peanuts, salt, and oil. Eaten in India and SE Asia. If eaten raw, it may grow in the mouth! **Medicinal:** Anticancer, increases immunity, highly effective for chronic fatigue, reduces swollen lymph glands, sore muscles, neuropsychological problems and pharyngitis, inhibits chromosomal damage from chemo and radiation therapy, restores mitosis in bone marrow, helps with Hep B. Extract heavily used for cervical cancer in Japan, antifungal, antiviral (HIV). Contains schizophyllan or sizofiran (1-3-alpha-D-glucarin-polysaccharide, or SPG). Dose 9-16 grams as decoction 3x/day. Tincture at 1:5. **Dyes:** Light brown. **Remediation:** Regarded for decolorizing paper and pulp mill effluent. **Other:** Most global mushroom.

Cultivation: LC best grown at 77°F (25°C), 5.5 pH, with mannitol or sorbitol substrate, and lots of B2 and B6. Schizophyllan produced at 13.95 g/L with LC formula of oleic acid – 0.1% (v/v), folic acid – 1.5 mg/L, citric acid – 0.2% (m/v), α-NAA – 0.2 mg/L, L-glutamic acid – 1.0 mg/L, CMC – 0.8% (m/v), and Tween 80 – 5 ml/L.



N.26 – *Schizophyllum commune*, the Split Gill Mushroom.

Serpula lacrymans (Wulfen) J. Schröt.

Dry Rot fungus

Spores: 8–12.5x4–6 µm, elliptical, smooth, thick-walled, orange-brown/orange-yellow. **Stalk:** Typically absent, white/grayish mycelial strands common, rhizomorphs can extend for meters. **Pores:** 1 mm deep, large, not tubes but irregular honeycomb-like network of folds, olive-yellow/brownish-yellow/rusty-brown/orange-brown/cinnamon, flesh thin, spongy, odor unpleasant/musty.

Range: Himalayas, North America, Czech Republic, East Asia. **Ecology:** Wood in old houses/buildings/poorly ventilated areas. **Season:** Year-round indoors.

Edibility: Inedible. **Medicinal:** Anticancer, antimicrobial, essential oil contains 19 constituents. **Remediation:**

Chromated copper arsenate, PAHs. **Other:** Destroys buildings. Growth is greatly increased by infrared rays (see *The EZ Theory of Hyphal Extension*, Chapter 1).

Sparassis radicata Weir
Western Cauliflower Mushroom

Spore Features: 6–7x4–5 µm, smooth, broadly elliptical, inamyloid, whitish. **Fruit Body:** 10–60 cm, tightly packed branches that arise from a common basal structure, branches fairly short and tightly packed, thin, whitish/yellowish/tan, evenly colored.

Range: Temperate Europe, North America. **Ecology:** Pathogenic and saprobic on roots/base of conifers (pines/Douglas-fir) and occasionally hardwoods, causing a brown/butt rot. **Growth Habit:** Solitary. **Season:** Late fall–early winter, annually recurring.

Edibility: Yes—floral notes, exceptional. **Medicinal:** Closely related *S. crispa* is antifungal, antibacterial, antitumor, and helps prevent stroke and hypertension, promote wound healing, and suppress blood sugar levels. **Remediation:** Uptakes arsenic. **Other:** One of the few mushrooms that (usually) can safely be identified with photos. *S. crispa* and *S. spathulata* grow in eastern North America.

Cultivation: Tricky indoors, similar to Maitake. Easier on oak/fir stumps outside. Cultures best taken from upper stem base. Hardwood strains are easier to cultivate than those found on conifers.

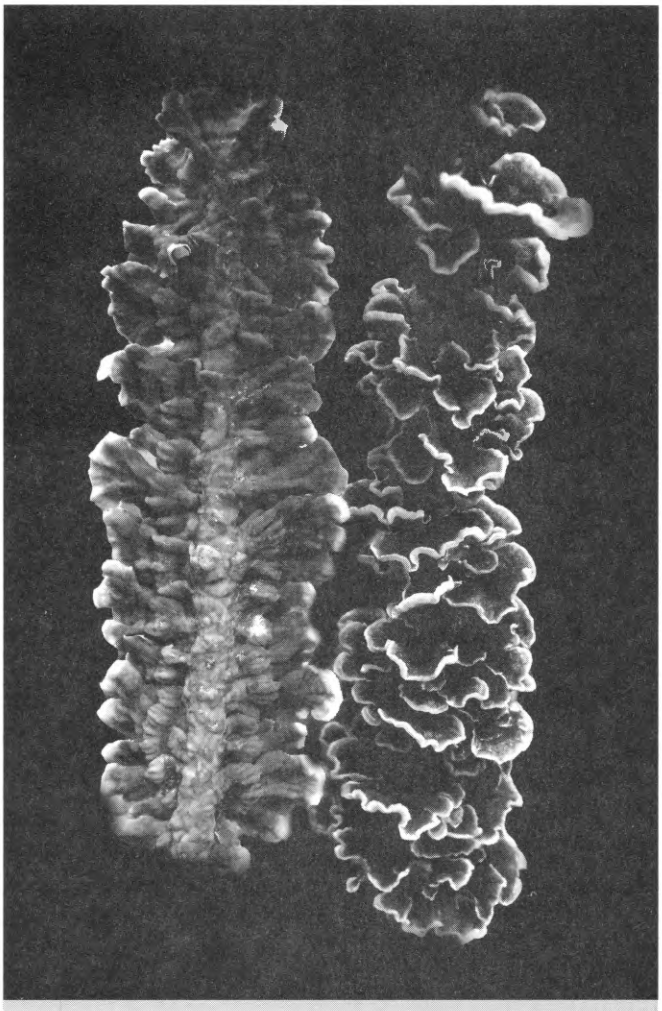
N.27 – *Sparassis radicata* looks like egg noodles and is easy to ID.

Stereum hirsutum (Willd.) Pers.
False Turkey Tail, Hairy Stereum, Hairy Parchment

Spores: 5–8x2–3.5 µm, smooth, cylindrical/narrowly elliptical, amyloid, white. **Fruit Body:** ≤3 cm, often fused with others, fan-shaped/semicircular/irregular, densely velvety/hairy/with appressed hairs, with concentric zones, yellow/tan/brown/reddish-brown/buff, laterally attached, KOH red/black on all surfaces. Flesh tough. **Pores:** Smooth, yellowish/yellow-brown/grayish brown, sometimes bruising darker yellow.

Range: North America. **Ecology:** Saprobic on branches and twigs of hardwoods (oaks/hornbeam), causing a white rot of the heartwood. Often hosting algae. Occasionally parasitized by jelly fungi. **Growth Habit:** In dense groups/masses. **Season:** Year-round.

Edibility: Too tough to eat. **Medicinal:** Antibiotic, antioxidant, anticancer. **Other:** May be a complex of species, with *S. complicatum* and *S. gausapatum*, among others, contributing to the continuum.



N.28 – *Stereum hirsutum*.

TERFEZIA ARENARIA (Moris) Trappe
Desert Mushroom, Moroccan Desert Truffle

SPORES: 19–26 µm, whitish/ochreous, globose, warty. **FRUIT BODY:** 3–15 cm, subglobose, smooth, unpolished, sometimes cracked. Thin walled (20–50 µm diameter), yellowish in the outermost layers, gleba solid, fleshy, succulent, whitish/pale pink/grayish/reddish brown, inner fertile tissue separated by sterile veins. Odor faint, taste mild.

RANGE: North Africa and Middle East. **ECOLOGY:** Sandy ground/grasslands/open stands of oak/pine/eucalyptus/*Cistus*/rockrose. **SEASON:** Winter/spring.

EDIBILITY: Choice. **MEDICINAL:** Antioxidant, antimicrobial. **OTHER:** Famous fungus of antiquity. Called *hydnon* by the Greeks, *tuber* by the Romans, and *terfex* in Islamic countries, where it is still popular.

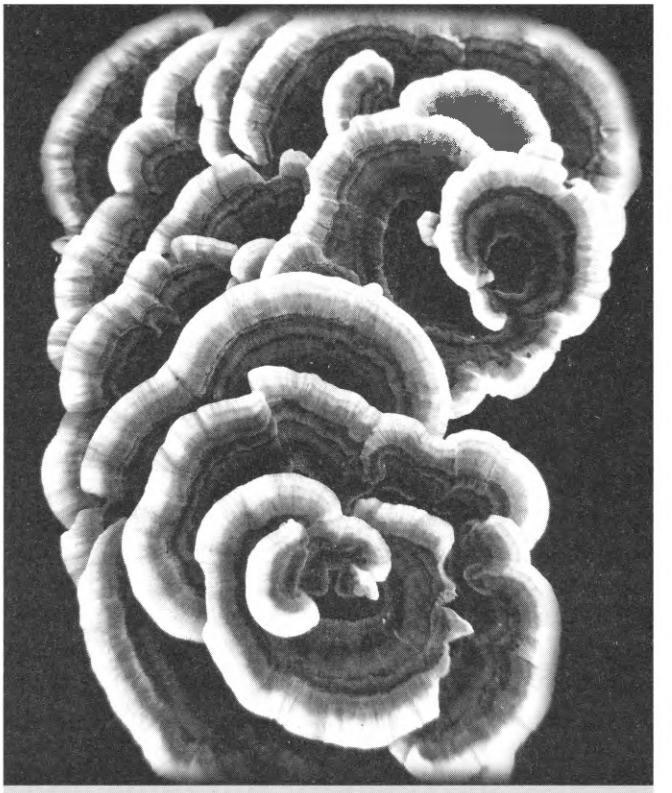
TRAMETES VERSICOLOR (L.) Lloyd
Turkey Tail, Many-Colored Polypore, China: *Yun Zhi*, Japan: *Kawaratake* (Cloud Mushroom)

SPORES: 4–6x1.5–2.5 µm, white/yellowish, cylindrical/sausage, smooth. **STALK:** Absent/rudimentary. **FRUIT BODY:** 2–10 cm broad, 1–2 mm thick, bracket-like, thin, leathery when fresh, rigid/slightly flexible dry, plane/wavy, dry, velvety, zoned with bands of contrasting colors, hairy zones alternate with smooth ones, variable colors: white/gray/brown/yellowish/buff/blush/reddish/dark brown/black, with a white margin, flesh tough and white, KOH negative/yellowish. **PORES:** 3–5/mm, white/yellowish, visible. Tubes up to 2 mm, long and tough.

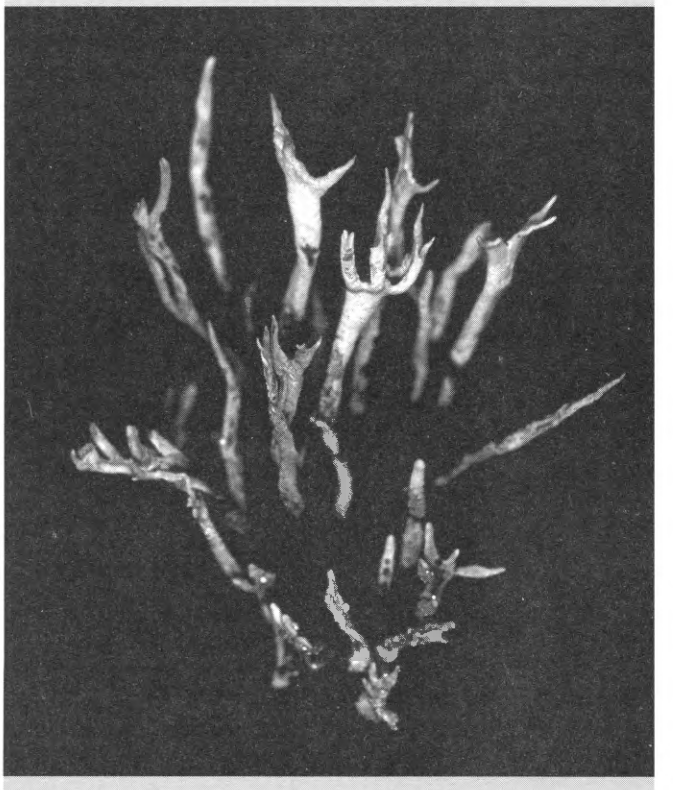
RANGE: Global, in boreal, temperate, subtropical, and tropical regions. **ECOLOGY:** Dead hardwoods/conifers. **GROWTH HABIT:** In groups/rows/shelving masses/clusters. **SEASON:** Year-round.

EDIBILITY: Best in soups, teas. **MEDICINAL:** Strong immune stimulation. In Japan: common for chemo/cancer patients (colorectal, small cell lung, leukemia, liver, gastric, nose and throat, esophagus, melanoma, and stomach). Antitumor, antibiotic, antiviral (HIV, HSV), antioxidant, antifungal, vasodilating. Helps with autoimmune diseases, lupus, chronic rheumatoid arthritis, sclerosis, Behcet's disease, Hepatitis B, malaria. hypertension, diabetes, thrombosis. Lowers cholesterol, speeds burn recovery. **DYES:** Ammonia=brown/beige, no mordant=gray-yellow. **REMEDIATION:** Thoroughly investigated, highly regarded. Breaks down all 16 priority PAHs and many aromatic compounds (e.g. nerve agents, dioxin, persistent organophosphates, PCPs, TNT, 3,4-dichloroaniline, dieldrin, antracines, pyrenes). Sorbs chromium and mercury from water. **OTHER:** Colors reflect mineral content of substrate.

CULTIVATION: Fast growing, with rubbery mycelium in age. Good for plain, pasteurized sawdust/logs of many wood types.



N.29 – *Trametes versicolor*, a beautiful and medicinal gift of the woods.



N.30 – *Xylaria hypoxylon*.

Xylaria hypoxylon (L.) Grev.

Candlestick Fungus, Candlesnuff Fungus, Carbon Antlers, Stag's Horn Fungus

Spores: Sexual spores 10–14x4–6 µm, bean-shaped, smooth, black. Asexual spores smooth, elliptical, white. Perithecia in upper half of mature fruit body. **Fruit Body:** Lower sterile portion 1–5 mm thick, black, minutely hairy, very tough/wiry. Upper 2–8 cm high, very tough, erect, slender, cylindrical becoming antler-like, tips white and powdery when young, eventually blackening. Flesh tough and white/pallid. **Other:** Reported to have luminescent mycelium.

Ecology: Rotting logs/stumps. **Growth Habit:** Scattered/densely gregarious/clustered. **Season:** Spring–winter.

Edibility: Not poisonous but very tough.

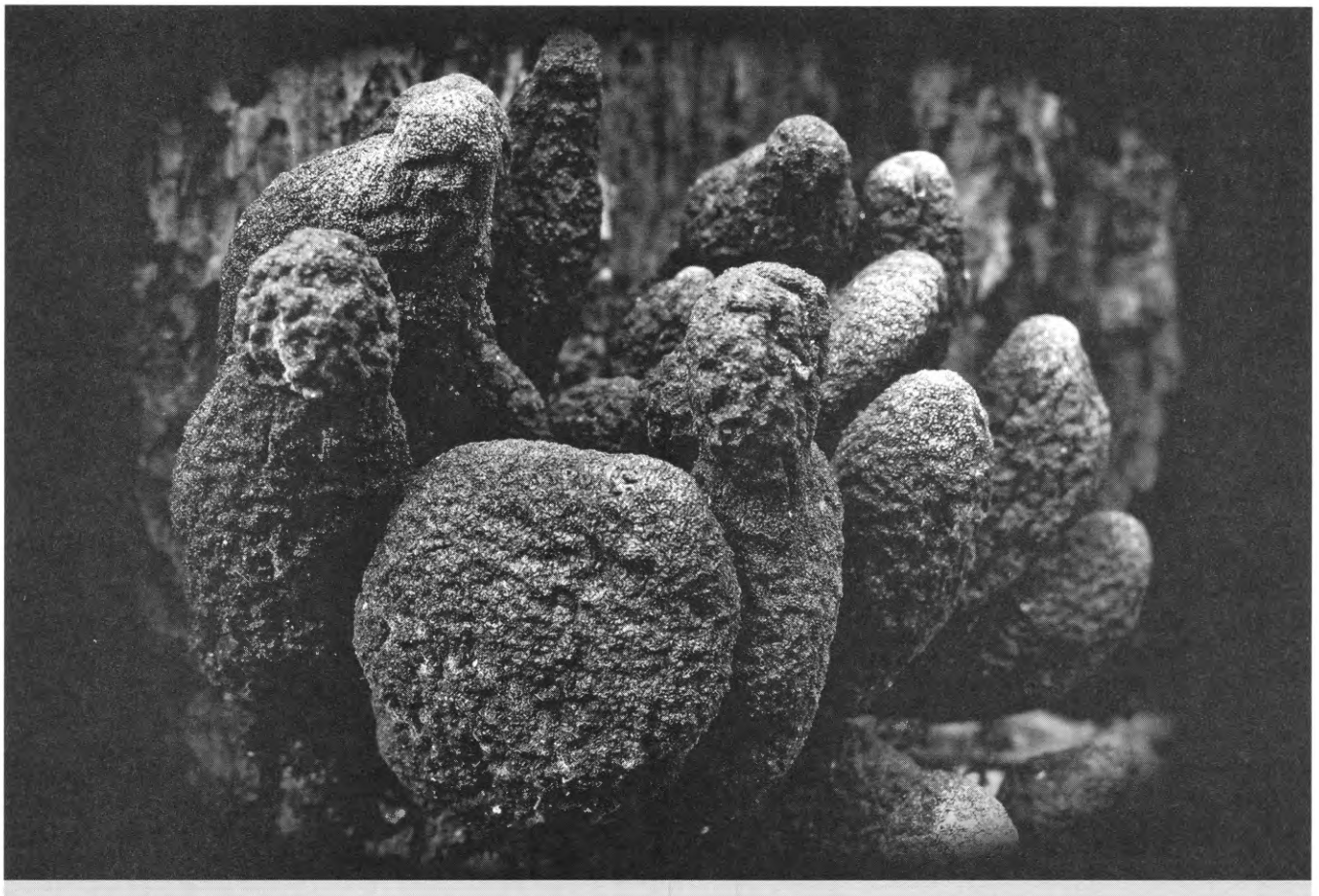
Xylaria polymorpha (Pers.) Grev.

Dead Man's Fingers, India: *Phoot Doodh* (To Gush Milk)

Spores: Sexual are 20–32x5–12 µm, spindle-shaped, smooth, dark brown/black. Asexual spores smaller, elongated/elliptical, smooth, hyaline under microscope. Perithecia in upper half of fruit body. **Stalk/ Fruit Body:** Short, well defined, narrower upper half. **Top:** 2–8x0.5–3 cm, tough and hard, erect, club-shaped/irregular/twisted, blunt/rounded/lobed, surface crust-like, wrinkled/cracked, black in age, flesh hard and white/pallid. Often covered with a white/gray/brown powder when young. **Other:** Asexual (whitish) stage in spring, sexual (carbon) stage the following summer.

Ecology: On rotting hardwood stumps/logs of beech/maple. **Growth Habit:** In groups/clusters. **Season:** Summer–fall.

Edibility: Too tough to eat. **Medicinal:** In Ayurvedic medicine: ground with sugar and formed into pea-sized pills. Anticancer, antifungal, antibacterial, antiviral (HIV), antioxidant, potential for memory conditions. Mycelium powder is said to produce a tranquilizing effect on the CNS. Improves sleep, reduces abnormal dopamine stimulation, improves iron deficient anemia, restores hormonal imbalance associated with menopause, prostate hypertrophy, and abnormal menstruation. Closely related *X. nigripes* is commonly cultivated in China for medicine.



N.31 – *Xylaria polymorpha*, the fingers of dead men.

Cap and Stalk

Agaricus arvensis Schaeff.
Horse Mushroom

Spores: 7–8.5x5–6 µm, smooth, elliptical, chocolate-brown. **Stalk:** 5–17x1–3 cm, slightly bulbous, thick/hollow, smooth/with cottony scales below ring, white/yellow. **Cap:** 7–20 cm, oval, broad/convex/plane, dry, smooth/small central scales, creamy/buff/yellowish, margin sometimes with veil remnants, thick flesh, firm, white, almond/anise scent, purple-brown in KOH. **Veil:** Membranous, white/yellow, cottony underside, often split with spoke-like pattern, forms a thick annulus. **Gills:** White, close, wide, free at maturity, pale/grayish/chocolate brown.

Range: North America, Europe, Asia. **Ecology:** Grassy areas, often near nettles and spruce. **Growth Habit:** Solitary/scattered/many. Occasionally forming fairy rings. **Season:** Late Sept. in Catskills, June–Oct. in New York, Nov.–Apr. in California.

Edibility: Excellent, almond-like, sweet, strong flavor. Can contain cadmium—eat in small amounts. **Dyes:** Salt water=yellow-tan on wool, iron pot=gray-green, brown when old.

C.1 – *Agaricus arvensis.*

Represented species

Agaricus arvensis
Agaricus augustus
Agrocybe aegerita
Agrocybe praecox
Albatrellus ovinus
Amanita caesarea
Amanita muscaria
Amanita pantherina
Amanita phalloides
Amanita virosa & allies
Armillaria mellea & allies
Boletus edulis
Cantharellus cibarius & allies
Chlorophyllum rachodes
Clitocybe nuda
Clitocybe odora
Coltricia cinnamomea
Coprinus comatus
Craterellus cornucopioides
Flammulina velutipes
Galerina marginata
Gomphidius glutinosus
Gomphus clavatus
Gymnopilus junonius
Hydnum repandum
Hypholoma capnoides
Hypholoma fasiculare
Hypsizygus ulmarius
Laccaria laccata
Lactarius rubidus
Lactarius rufus
Lentinula edodes
Lyophyllum decastes
Macrolepiota procera
Marasmius oreades
Neolentinus lepideus
Omphalotus olivascens
Panellus stipticus
Pholiota nameko
Pleurotus ostreatus & allies
Psilocybe cubensis
Psilocybe cyanescens
Psilocybe mexicana
Russula xerampelina
Stropharia rugosoannulata
Suillus luteus
Tricholoma magnivelare
Volvariella bombycina
Volvariella volvacea

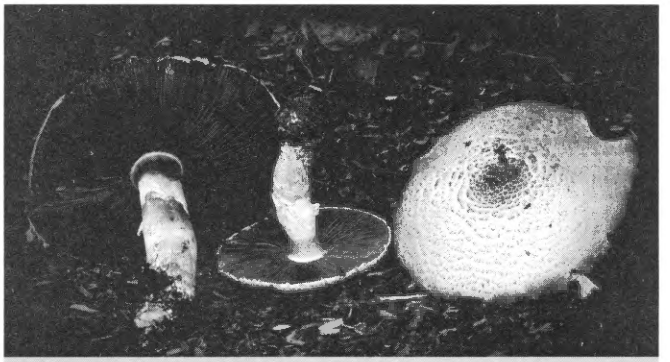
AGARICUS AUGUSTUS Fr.

Prince

SPORES: 7.5–10x5–6 µm, elliptical, smooth, chocolate-brown. **STALK:** 1–4x8–35 cm, often with thick annulus, white/yellow, smooth, equal, small scales at base. Flesh thick. **CAP:** 7–40 cm, thick flesh, marshmallow-shaped/hemispherical/convex/flat/uplifted, with many brown scales on a white background that yellows in age, bruises brown-yellow. Cuticle turns yellow in 10% KOH. Smells like almonds. **VEIL:** Partial veil with dark warts, membranous, white/brown, cottony, forming skirt-like annulus. **GILLS:** Close, free, pallid/grayish-brown/dark-brown.

RANGE: Warm weather North America, Canada, Rocky Mountains, Europe, North Africa, Asia. **ECOLOGY:** Clearings/along roads/flowerbeds/compost sites/disturbed soil/grassy areas/under deciduous/conifers (redwood). **GROWTH HABIT:** Solitary/in groups. **SEASON:** Spring–fall.

EDIBILITY: Meaty, excellent. **DYES:** Iron=light brown.



C.2 – *Agaricus augustus.*

AGROCYBE AEGERITA (V. Brig.) Singer

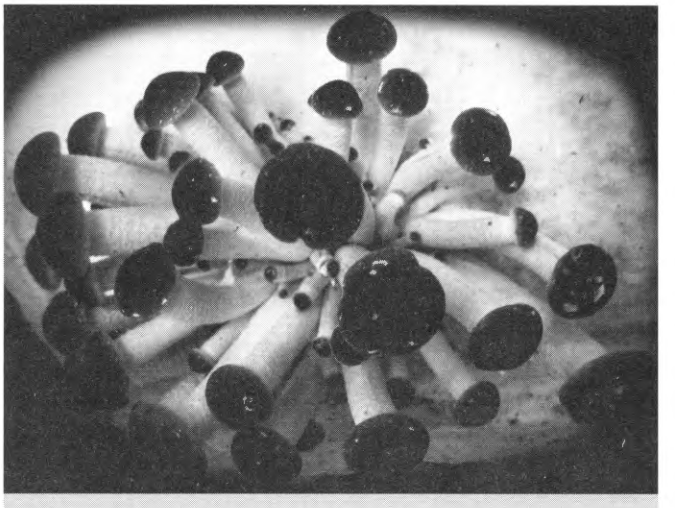
Pioppino, Chestnut Mushroom, Swordbelt, Fungi Populi, Chinese: *Zhuzhuang-tiantougu* (South Poplar Mushroom)

SPORES: 8–11x5–7 µm, elliptical brown. **STALK:** White, membranous ring on top. **CAP:** 3–10 cm, convex/flat, yellowish/chestnut brown. **GILLS:** Close, broad, adnate/seceding, pale/gray/brown.

RANGE: USA, Japan, Korea, Australia, China, Mexico, Europe. **ECOLOGY:** Poplar/box elder/willow, in clusters. **SEASON:** Spring–late fall.

EDIBILITY: Excellent—pork-like. Contains B5, folate, biotin, niacin, selenium, potassium, and rioboflavin. **MEDICINAL:** Anticancer, antifungal, anti-inflammatory, antibiotic, helps suppress cholesterol absorption. In Fiji: used to strengthen the spleen and stop diarrhea. Cold water extract inhibits leukemia U937 in mice. DNA-protecting properties. Optimal glucan extract at 7.5 pH and 90°C for 1 hour.

CULTIVATION: Easy and rewarding. Grows on straw. Mycelium in LC produces dark reddish exudates that colors broth. Casing optional. Horizontal surface preferred. Good for stumps/logs.



C.3 – *Agrocybe aegerita.*

AGROCYBE PRAECOX (Pers.) Fayod

Spring *Agrocybe*

SPORES: 8–12x5–7 µm, elliptical, smooth, truncate from germ pore, brown. **STALK:** 3–13x0.3–1 cm, equal/tapered/slightly enlarged at base, white/pallid/brownish, fibrillose, striate, base often with white mycelial threads. **CAP:** 3–10 cm, convex/umbonate/plane/uplifted, dry/slightly tacky, smooth/cracked, creamy/tan/olive, veil remnants often on margin, not striate, flesh white/pale yellow, odor mild/cucumber, taste mild/bitter. **VEIL:** Membranous, thin, may form annulus. **GILLS:** Close, broad, adnate/seceding, pallid/light brown/grayish/dull brown.

RANGE: North America, Europe, North Africa. **ECOLOGY:** Open woods/cultivated areas/roadsides. Under mountain conifers/maples in spring. **GROWTH HABIT:** Solitary/scattered/gregarious. **SEASON:** Spring–fall.

EDIBILITY: Y—poor flavor. **MEDICINAL:** Strengthens spleen, stops diarrhea. Antitumor, antiviral, immunomodulant.

C.4 – *Agrocybe praecox.*

ALBATRELLUS OVINUS (Schaeff.) Kotl. & Pouzar

Sheep Polypore

SPORES: 3–4.5x2.5–3.5 µm, elliptical/round, smooth, not amyloid. **STALK:** 3–10x1–4 cm, thick, central/off center, smooth, equal/enlarged below with narrowed base, solid. Flesh white, firm, whitish/tinged cap color/pinkish. **CAP:** 4–20 cm, circular/irregular, convex/slightly depressed/flat. Dry, smooth, scaly in age, flesh thick, firm, whitish/tan/pinkish/purplish/gray. **PORES:** 2–4/mm, minute, round. Tubes 1–2 mm deep, usually decurrent, white/yellow.

RANGE: Widely distributed, Rocky Mountains, Maine, Europe, SE U.S. **ECOLOGY:** On ground in mixed woods. Associated with spruce, Manzanita, and conifers. **GROWTH HABIT:** Solitary/scattered/gregarious, sometimes in fused masses. **SEASON:** July–Dec.

EDIBILITY: Yes—best young, slimy. Good preserved in oil. Can be a laxative in large amounts. **MEDICINAL:** Antioxidant, lowers cholesterol, anticancer (leukemia, cervical, breast, colon, lymphoma), anti-inflammatory. Promotes melanin synthesis. Homeopathic preps suggested for rheumatoid arthritis, septic shock, and inflammation. Contains Grifolin. **REMEDIATION:** Accumulates nickel (0.72 mg/kg) and selenium. Produces esterases, lipases, and carboxyl esterase used in industrial processing of materials and sewage treatment.

C.5 – *Albatrellus fletii*, a relative of *A. ovinus*, has a blueish cap.

AMANITA CAESAREA (Scop.) Pers.

Ceaser's Amanita

SPORES: 8–12x6–8 µm, white/faint yellow, elliptical, smooth, not amyloid, stain purple in iodine. **STALK:** 5–20x1.5–3 cm, equal/thicker below, smooth/with small scales, gill color/paler, pith/jelly inside, eventually hollow. **CAP:** 7–25 cm broad, oval/convex/flat, slightly viscid when moist, smooth/with one or two thick white veil tissue pieces, bright red/orange/yellowish, striate margin. Flesh thick, yellow under cuticle, elsewhere white. **VEILS:** Partial veil membranous, usually forming a striate, gill-colored, skirt-like ring high on stalk. Universal veil thick, white, membranous, forming a tough, lobed, large, sac-like volva attached to the stalk base. **GILL:** Adnate/adnexed/free, close, broad, chrome yellow/pale yellow with darker edges.

RANGE: North America, Arizona, New Mexico, Europe, Quebec, North Africa, Mediterranean. **ECOLOGY:** Sandy/slightly acidic soil under pines/hardwood trees, especially oak. **GROWTH HABIT:** Scattered/gregarious/in large rings. **SEASON:** Spring–fall.

EDIBILITY: Choice. Contains important essential fatty acids required for human health. Can be high in cadmium and lead. **MEDICINAL:** High antioxidant capacity and antimicrobial activity.

C.6 – *Amanita caesarea* has a prominent volva and reddish cap.

AMANITA MUSCARIA (L.) Lam.

Fly Agaric, Germany: *Fliegenpilz*, Austria: *Hexenpilz* (Witch's Mushroom), Basque: *Amoroto* (Toad-Like Thing), Russia: *Mukhomer*, Lithuania: *Musiomeris*, Danish: *Flue-Svamp*, Italian: *Moscario*, French: *Tue Mouche*, Japan: *Hayetoritake* (Fly Destroying Mushroom) or *Beni Tengu Take* (Scarlet Goblin Fungus), Hungary: *Bolond Gomba* (Mad Mushroom), Philippines: *Ampacao*

SPORES: 9–13x6.5–9 µm, broad, elliptical, smooth, not amyloid, white. **STALK:** 5–30x1–4 cm, tapering upward/equal with basal bulb, white/off white, smooth/scaly below ring, fragile in age, slightly brittle. **CAP:** 5–40 cm broad, round/convex/flat/upturned, flesh firm/soft, bright red/orange, white

universal veil remnants in stellar formation. **Veils:** Partial veil membranous, often forming a skirt-like, thin, persistent, and white annulus on upper stalk. Universal veil friable, forming a scaly volva with 1-4 concentric rings. **Gills:** White, adnate/adnexed/free, close, broad.

Range: North America, Europe, Asia. **Ecology:** Associated with pine/spruce/fir/birch/madrone/oak/poplar/beech/larch/fir/hornbeam/aspen/conifers. **Growth Habit:** Solitary/scattered/gregarious/in rings. **Season:** July–Oct.

Edibility: Psychoactive, see Chapter 12. Edible and non-psychoactive if parboiled. Added to vodka in Russia. In the Shutul Valley of Afghanistan: boiled with fresh jewelweed and soured goat cheese brine. Traditional ales produced with dried *A. muscaria*, fireweed, and cow parsnip. **Medicinal:** Used for paralysis, epilepsy, chronic catarrh, ringworm, night sweats, cancer, and muscle twitching in the face, forehead, and eyes. In Traditional Chinese Medicine: used for eczema. Steam distillation produces amanitol, a camphor-like substance. **Remediation:** Highly tolerant of mercury and cadmium. Accumulates thorium. Can degrade the PAHs phenanthrene and chrysene. **Dyes:** Light yellow-beige.

Cultivation: Being ectomycorrhizal, *A. muscaria* needs to form a symbiosis with a living plant to produce fruiting bodies. The mycelium slowly grows in isolation on very specific media. The best option is to inoculate pine or birch saplings with spores in the spring.

C.7 – *Amanita muscaria* in various stages of growth.

Amanita pantherina (DC.) Krombh.
Panther Cap, False Blusher

Spores: 9–13x6.5–9 µm, white, elliptical, smooth, not amyloid, white. **Stalk:** 5–20x1–3 cm, tapering upward/equal with bulb at base, dry, white/buff, smooth above ring, usually scaly below. White/grey volva, forming ≥1 rings above the base bulb, flesh white and non-staining. **Cap:** 4–25 cm broad, round/convex/flat/depressed, viscid when moist, dark/light brown/tan/dull yellow, center darker, with white veil remnants, striate margin. Flesh firm and white. **Veils:** Partial veil white, membranous, leaving a strong annulus with ragged margin. Universal veil friable, white, forming a collar-like volva that may be scaly/ragged above rim and with/without a free rim. **Gills:** Adnate/adnexed/free, white/pale, close/slightly attached.

Range: Europe, western Asia, North America. **Ecology:** On ground in woods (pine/oak/beech/Douglas-fir). **Growth Habit:** Solitary/scattered/gregarious. **Season:** June–Oct.

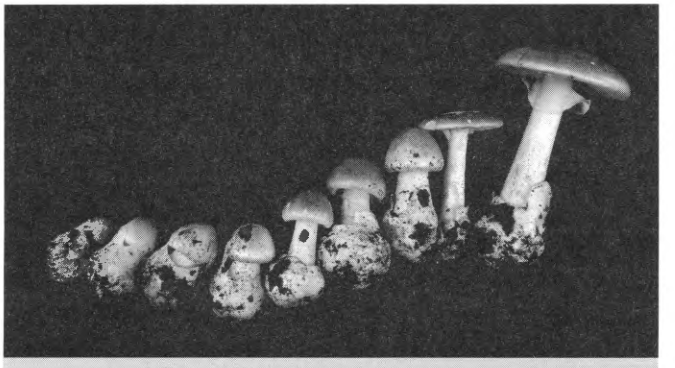
Edibility: Associated with many mushroom poisonings. Contains psychoactive compounds, see Chapter 12.

Amanita phalloides (Vaill. ex Fr.) Link
Death Cap

Spores: 7–12x6–9 µm, broad, roundish, smooth, amyloid, white. **Stalk:** 5–18x1–3 cm, tapering up/equal with large base, white/cap color, smooth/with little scales, hollow/solid. **Cap:** 4–16 cm broad, oval/convex/plane, smooth, with small fibers, viscid/sticky when moist, shiny/metallic when dry, variable color from green/brownish-olive/yellow-green/yellowish/white, darker center, margin not striate, flesh white. **Veils:** Partial veil membranous, white/yellow-green, may form fragile annulus. Universal veil membranous, white, forming a sac-like volva that is thin, fragile, and usually buried. **Gills:** Adnate/adnexed/free, close, white/faintly green, stains pale lilac/pink with sulfuric acid.

Range: North America, Europe. **Ecology:** Under/near oak/beech/chestnut/horse chestnut/birch/filbert/hornbeam/spruce/pine/hemlock/hazel/cottonwood. **Growth Habit:** Solitary/scattered/in groups. **Season:** Late spring–late autumn.

Edibility: Deadly poisonous! Symptoms are delayed, not appearing from 6–24 hours after eating. Flavor is reportedly good. **Medicinal:** Homeopathic for liver damage, paralysis, or physical deterioration. Other extracts have shown significant antitumor effects (colon, breast, and tongue). Immune boosting, treats acute yellow atrophy and liver jaundice.



C.8 – *Amanita phalloides*, the Death Cap Mushroom.

AMANITA VIROSA Secr. *& ALLIES*

Destroying Angel

SPORES: 9–11x7–9 µm, round, smooth, amyloid, white. **STALK:** 7.5–20x0.5–2 cm, narrow at top sometimes enlarging downward to basal bulb, cottony/shaggy, white, with ring and cup, hollow, wooly surface. Flesh white. Odor not pleasant. **CAP:** 5–12.5 cm broad, convex/flat, never fully opened, tacky when wet, smooth, dull/shiny white, center may discolor in age. **VEILS:** Partial veil membranous, white, forming thick annulus on upper stalk. Universal veil white, forming membranous, large, sac-like volva. **GILLS:** Free, pruinose, white, crowded, narrow/moderately broad.

ECOLOGY: Sandy, acid soils, near broadleaf trees in mountainous and cooler climates. **GROWTH HABIT:** Alone/in small, scattered groups. **SEASON:** Late June–early Nov.

EDIBILITY: Deadly poisonous! **OTHER:** Similar in appearance to the poisonous species *A. bisporigera, A. veran,* and *A. ocreata.*

C.9 – *Amanita bisporigera,* one of the Destroying Angels.

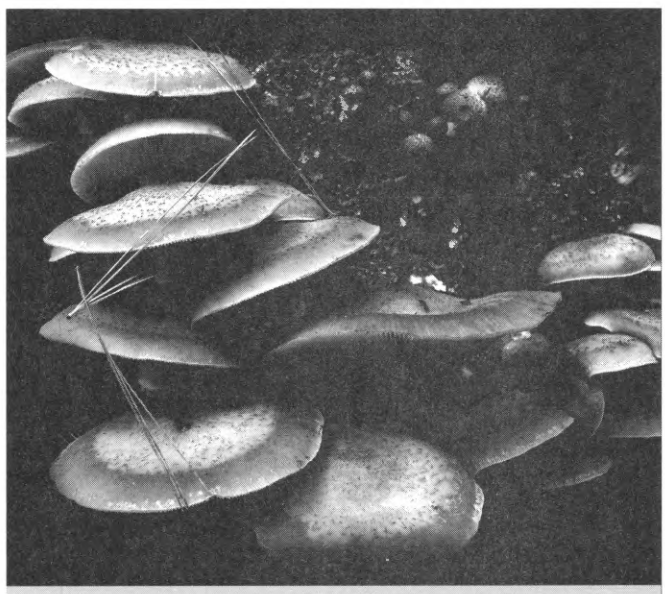
ARMILLARIA MELLEA (Vahl) P. Kumm. *& ALLIES*

Honey Mushroom, Germany: *Honigpilz, Hallimasch* (Hell in the Ass), Chinese: *Mihuanjun,* Czech: *Václavka,* Dutch: *Honingzwam,* Finnish: *Mesisieni,* French: *Armillaire, Pivoulade,* Italian: *Chidini Famigliola Buona,* Polish: *Opienka, Miodowa,* Russian: *Opyenok,* Spanish: *Miel,* Swedish: *Honungsskivling*

SPORES: 7–9x5–6 µm, smooth, elliptical, white. **STALK:** 10–20x1.5–5 cm, club-shaped, curved, striate at top, with/without white ring, thick, tough, hard when dry, equal/narrow at base, white/pallid/ochre/cinnamon, scaly, fibrillose, odor oily and unpleasant. Flesh white. **CAP:** 3–15 cm broad, globose/depressed, cuticle white/cinnamon/pinkish-brown/yellow-brown, sticky when moist, with fibrils, margin inrolled/uplifted, flesh thick, firm, and white, odor spicy-fruity/cucumber/watermelon/rotten potatoes. **VEIL:** Membranous, white with cottony ring that is flaring/against stalk and cap color. **GILLS:** Adnate/adnexed/notched, close, white/pale yellow/rusty-brown/cinnamon.

RANGE: North America, Rocky Mountains, Sierra Nevada, Pacific NW, coastal California, Japan. **ECOLOGY:** Parasitic on wood, but also a symbiotic cosmopolitan, in forests/sandy soil/thickets/pine woods. On conifers/Douglas-fir/pine/oak/ericaceous shrubs (rhodoendron, huckleberry)/tan oak/madrone/mazanita/pine. Forms thick black rhizomorphs that girdle trees. **GROWTH HABIT:** In dense clumps or tufts. **SEASON:** Summer–winter.

EDIBILITY: Yes, when cooked. Taste mild/nutty/bitter, though some consider them better than Chanterelles. Chewy, spicy odor. Not advised with alcohol. Almost 30% protein. **MEDICINAL:** Anticancer, nerve-relaxing, increases cerebral blood flow, increases oxygen use in the heart without decreasing blood pressure, increases blood flow to brain and heart without increasing blood pressure. Polysaccharides helpful post radiation exposure, anti-epileptic, anti-aging, immunomodulating, antivertigo, insomnia, intestine and stomach distress, poor night vision, antitumor. Reduces peripheral and coronary vascular resistance, increases cerebral blood flow, prevents respiratory and digestive tract conditions, and reduces peripheral and coronary vascular resistance. In Traditional Chinese Medicine: known as *mi huan ku,* used as a nutritive tonic for dizziness, headache, neurasthenia, insomnia, limb numbness, convulsion in infants, weak vision, and dry skin. Calms liver yang and supports internal wind. Melleolide (in mycelium) is antibiotic. **OTHER:** The *Armillaria* complex includes 10 species once lumped together as *A. mellea.* It has many look-alikes. Rhizomorphs can extend 100 meters or more. Mycelium is luminescent, with an optimal temperature of 77°F (25°C). The light can penetrate cardboard and develop photographic plates. Complex includes the largest living organism in the world.



C.10 – *Armillaria solidipes,* from the Honey Mushroom complex.

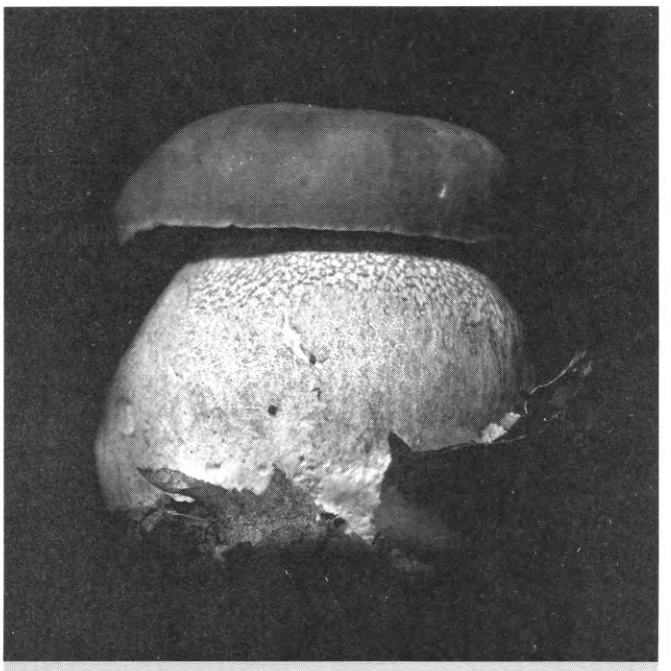
Boletus edulis Bull.

King Bolete, Cep, Steinpilz, Squirrel's Bread, Penny Bun, Chinese: *Meiwei Niugan*, Czech: *Hrib Smrkovy*, Dutch: *Eekhoornt Jesbrood*, Finnish: *Herkkutatti*, French: *Cèpe*, German: *Steinpilz*, Italian: *Porcino* (singular), *Porcini* (plural), Polish: *Borowik*, Russian: *Byelii, Greeb*, Spanish: *Rodellón*, Swedish: *Stensopp*

Spores: 13–19x4–7 µm, spindle-shaped/elliptical, smooth, olive-brown. **Stalk:** 8–25x2–12 cm, bulging, firm, entirely white/white at base and brownish above, may have reticulation on upper half. **Cap:** 8–30 cm broad, convex/plane, dry, viscid when wet, smooth/pitted, may crack in dry weather, color variable: whitish/pinkish/yellow/cinnamon-brown/reddish-brown, margin paler, odor and taste pleasant. Flesh thick and white/yellowish/light red. **Tubes:** Sunken around stalk, small and round, white/pallid/yellow/olive-yellow/brown.

Range: North America, Europe, Mexico, Asia, India, New Zealand. **Ecology:** Associated with pine/hemlock/spruce/fir/birch/aspen/oak/conifers above 1,000 feet. **Growth Habit:** Solitary/scattered in groups. **Season:** Spring/late summer–first frost.

Edibility: Choice, sweet, delicious. Odor like hazelnuts. Highest selenium content of any mushroom, accumulates gold at 235 ng/g. High in protein, vitamins, minerals, and dietary fiber. **Medicinal:** Vasoprotective, anticancer. If attacked by *Hypomyces chrysospermus*, sprinkle on wounds to stop bleeding. Antitumor, highly antioxidant. In Traditional Chinese Medicine: used in Tendon Easing Pills for lumbago, pain, and numb limbs, leucorrhea, and tetany. **Dyes:** Ammonia=chrome-mustard. **Remediation:** Mercury ≤250x, cadmium ≤10x.



C.11 – *Boletus edulis* in all its pudgy glory.

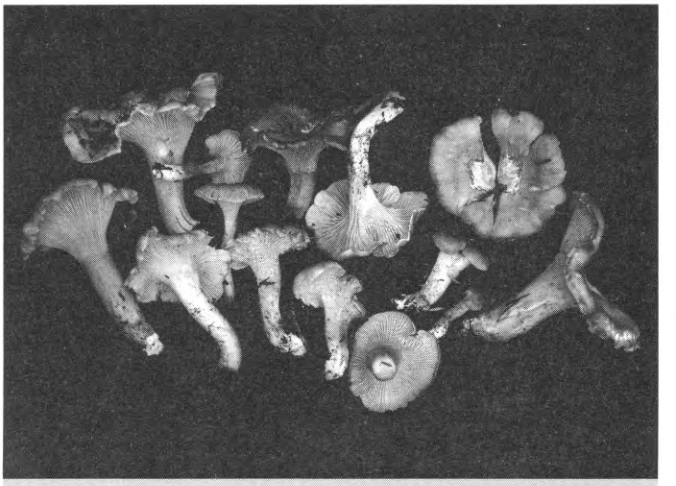
Cantharellus cibarius Fr. & Allies

Chanterelle, Russian: *Lisichki* (Little Fox), Chinese: *Liyoujun*, Czech: *Liska Obecná*, Dutch: *Hanekam, Cantharel*, Finnish: *Kantarelli*, French: *Girolle, Chanterelle Commune, Chevrette*, German: *Echter Pfifferling, Eirschwamm*, Italian: *Gallinaccio*, Polish: *Pieprznik*, Spanish: *Canterela, Cabrito*, Swedish: *Vanligkantarell*, Japanese: *Anzutake* (Apricot Mushrooms), Portugese: *Canarinhos* (Canary Bird Chicken), Chinese: *Jiyou-jun* (Chicken Fat Mushroom), Swahili: *Wisogolo*, Turkish: *Yumurta Mantasi*, Iceland: *Kantarella*

Spores: 7–11x4–6 µm, elliptical, smooth, creamy/yellow/pinkish. **Stalk:** 2–10x0.5–5 cm, equal/tapered down, solid, dry, firm, colored like cap/paler, often staining dark yellow. **Cap:** 3–25 cm, convex/plane/depressed/vase-shaped, smooth/cracked, margin often wavy, not viscid, orange/bright golden/yolk yellow/pale yellow. Odor mild/apricot-like, taste mild/peppery/bitter. Flesh thick, firm, whitish/yellowish/orange. **Gills:** Thick, well-spaced/close, shallow, blunt, fold-like, deeply decurrent, often forked/cross-veined, color like cap/dingy orange, brown in age. **Other:** Many closely related *Cantharellus* species have a similar appearance.

Range: Widespread, North America, Europe, Himalayas, Thailand. **Ecology:** Under old or second growth conifer/broadleaf trees (Douglas-fir/live oak/hemlocks/spruces). **Growth Habit:** Widely scattered on ground. **Season:** Varies by location. June–Sept in SE U.S., July–Aug in NE U.S., Sept–Nov in NW U.S., Nov–Feb in CA.

Edibility: Choice, peppery raw. High in vit. A and D2. Has eight essential amino acids, 21% protein. **Medicinal:** Antimicrobial, regulates calcium transportation, helps with dry skin, and eye inflammation. In Traditional Chinese Medicine: night blindness, tonifies mucus membranes, and protects against respiratory infection. **Dyes:** Ammonia=yellow. **Other:** Many closely related species have similar gill/ridge, cap, and color characteristics. Annual North American commercial harvest=$2 billion.



C.12 – *Cantharellus formosus*, a close relative to *C. cibarius*.

CHLOROPHYLLUM RACHODES (Vittad.) Vellinga

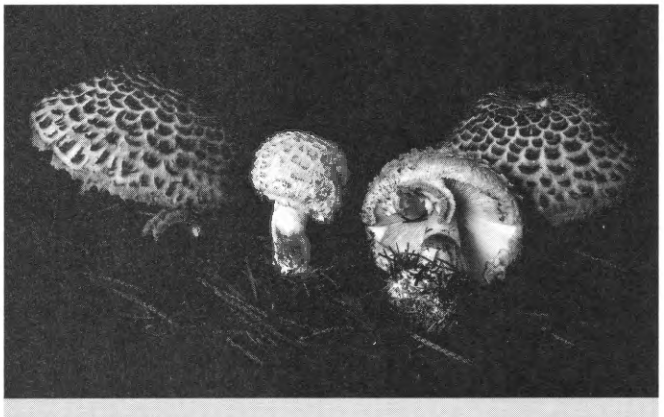
Shaggy Parasol, Czech: *Bedla Vysoká,* Dutch: *Knolparasolzwam,* Finnish: *Akan Sien,* French: *Lépiote Déguenillée,* German: *Safranschirmling,* Italian: *Mazza di Tamburo,* Polish: *Czubajka,* Russian: *Greeb-Zontik-Krasnye,* Spanish: *Apagador Matacandil,* Swedish: *Rodnande Fjällskivling*

SPORES: 10–14x5–8 µm, ellipsoid, smooth, hyaline in KOH, dextrinoid. **STALK:** 10–21x2–3.5 cm, club-shaped with basal bulb, bald, whitish above, brownish below, bruising brownish, with a high, double-edged, moveable, and brown-edge ring. **CAP:** 9–16 cm, convex/nearly round/broadly convex/flat/broadly bell-shaped, dry, soft, bald at first, soon breaking up into shaggy scales with brownish tips on a whitish background, KOH negative/pinkish on surface. Flesh whitish/pale brownish, staining pinkish-orange/reddish/brownish, thick. **GILLS:** Free, close/crowded, white/pale brownish, often with brownish edges.

RANGE: Temperate regions, North America, Europe, Southern Africa, Australia. **ECOLOGY:** Saprobic, in lawns and disturbed-ground, roadsides, gardens, field edges, near conifers (spruce). **GROWTH HABIT:** Alone/scattered/gregarious in troops or rings. **SEASON:** Spring–fall.

EDIBILITY: Tasty! **REMEDIATION:** Accumulates arsenic, lead, mercury, and copper. **OTHER:** *C. olivieri* and *C. brunneum* are closely related. Synonyms include *Lepiota rachodes* and *Macrolepiota rachodes.*

CULTIVATION: Cloned cultures often fail to regenerate. Starting strains from spores is preferable. Reported to grow in grass clippings outdoors.



C.13 – *Chlorophyllum rachodes.*

CLITOCYBE NUDA (Bull.) Cooke

Blewit, Blue Stalk, Czech: *Cirüvka,* Dutch: *Paarse Schijnridder,* French: *Tricholome Pied-Bleu,* German: *Violetter Rötelritterling,* Italian: *Agarico Violetto, Prugnolo* Polish: *Gaska,* Russian: *Ryadovka Fiolyetovaya,* Spanish: *Tricoloma,* Swedish: *Hostmusseron*

SPORES: 5.5–8x3.5–5 µm, elliptical, roughened, dull pinkish/pinkish/buff. **STALK:** 2.5–10x1–3 cm, equal/enlarged base, dry, fibrillose, purple/pale purple/colored like gills, base often with purple mycelium. **CAP:** 4–18 cm, convex and inrolled/broadly umbonate/plane/uplifted, wavy margin in age, smooth, lubricous/not viscid, lustrous when dry, purple/purple/brownish/grayish/flesh color/tan, margins remaining purpleish, odor faintly fragrant, taste pleasant/bitter. Flesh thick, soft purplish/lilac/buff. **GILLS:** Adnate/adnexed/notched/decurrent, purple/pale purple/bluish-purple/grayish-purple/buff/pinkish-buff/brownish.

RANGE: North America, Europe, Australia. **ECOLOGY:** Broadleaf/coniferous woodlands (live oak/pine/cypress/fir)/decomposing sawdust piles/humus-rich ground/conifer duff/manure/compost. **GROWTH HABIT:** Scattered/gregarious, often in arcs/rings. **SEASON:** Aug.–Dec.

EDIBILITY: Slightly poisonous when raw. Should be cooked well. **MEDICINAL:** Regulates blood sugar and metabolism, antimicrobial, anticancer, high in vit. B1, antiviral, antibacterial, supports the nervous system. Several known compounds in essential oil. In homeopathy: treats insomnia, headaches, stimulate metabolism, opens 3rd eye. **DYES:** Ammonia+copper pot=grass green. **REMEDIATION:** Accumulates mercury (3.02 mg/kg) and arsenic. **OTHER:** *Lepista nuda* is a synonym.

CULTIVATION: Commercially cultivated in France. Prefers darkness at spawn run. Needs a cold shock to fruit on 10% horse manure/straw compost. Does well outdoors on hardwood leaf mulch and sawdust.

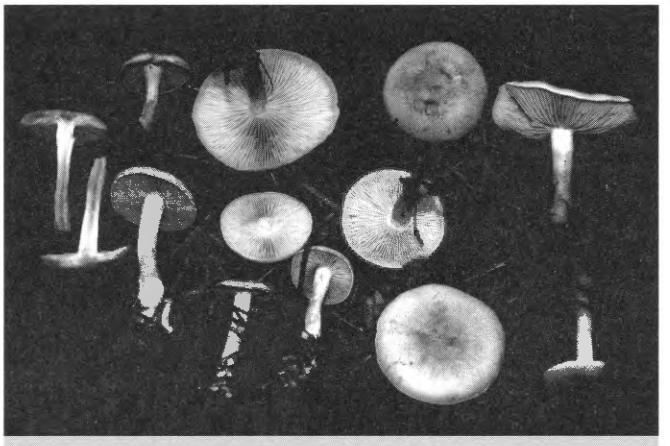
C.14 – *Clitocybe nuda,* the Blewitt.

Clitocybe odora (Bull.) P. Kumm.
Blue-Green Anise Mushroom

Spores: 6–8x3–5 µm, elliptical, smooth, pinkish cream/buff. **Stalk:** 2–9x0.5–1.5 cm, equalish, smooth, white/buff/cap color, surface rough. **Cap:** 2.5–10 cm broad, convex/plane/depressed, smooth, not viscid, blue-green/greenish-gray/grayish-brown. Odor strong and anise-like. Flesh white/tinged cap color. **Gills:** Adnate/decurrent, close, blue-green/greenish/dark green/whitish/pinkish-buff.

Range: Pacific NW, North America, Rocky Mountains, Europe, Asia. **Ecology:** Broadleaf/conifer woodlands. **Season:** Summer–fall, Nov.–Feb.

Edibility: Yes—strong flavor, best as a flavoring (dry and store as a condiment). **Medicinal:** Contains various essential oils, primarily p-anisaldehyde (81.4%).



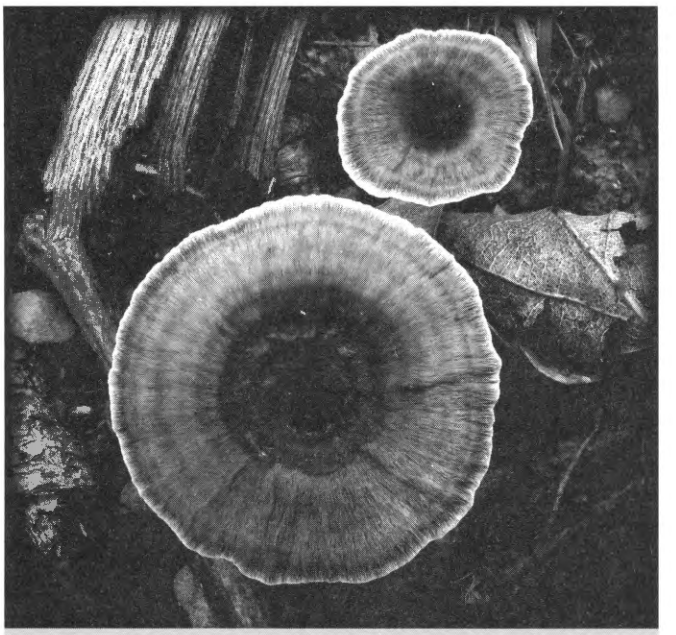
C.15 – *Clitocybe odora* has a rich scent of anise.

Coltricia cinnamomea (Jacq.) Murrill
Fairy Stool

Spores: 6–10 x4.5–7 µm, smooth, elliptical, weakly dextrinoid, yellowish-brown. **Stalk:** 1–5x1–4 mm, center/equal, brown/red-brown, velvety, tough. **Cap:** 1–5 cm broad, circular, centrally depressed, dry, yellow-brown/cinnamon/reddish-brown, with shiny/silky lines, concentric zones, margin often torn, flesh ≥1 mm, flexible when fresh, staining black in KOH. **Pores:** 2–3/mm, angular/circular, yellow-brown/brown/reddish-brown. Tubes 0.5–3 mm long, usually not decurrent.

Range: North America, Europe. **Ecology:** Apparently (facultatively) mycorrhizal, possibly saprobic. On ground/moss in woods, roads, paths, rarely on deadwood. **Growth Habit:** Solitary/in small groups. **Season:** Year-round.

Edibility: Too tough to eat. **Medicinal:** Anticancer. **Other:** Retains beautiful color when dry.



C.16 – *Coltricia cinnamomea*, the Fairy Stool.

Coprinus comatus (O.F. Müll.) Pers.
Shaggy Mane, Lawyer's Wig, Chinese: *Maotou Quisan*, Czech: *Hnojník Obecny*, Dutch: *Geschubde Inktzwam*, Finnish: *Suomuinen Mustasieni*, French: *Coprin Chevelu, Goutte d'encre*, German: *Schopftintling*, Italian: *Coprino Chiomato*, Polish: *Czernidlak*, Russian: *Navoznik Byelii*, Spanish: *Barbuda*, Swedish: *Fjälig Bläksvamp*

Spores: 10–18x7–9 µm, elliptical, smooth, black. **Stalk:** 5–40x1–2.5 cm, tapering up, smooth, white, hollow or pith-stuffed, easy to separate from cap, lacking pleurocystidia. **Cap:** 4–25 cm, cylindrical/bell-shaped, expanding, margin curling up, then deliquescing from bottom up, not viscid, white with scales, margin may be striate and tattered, flesh soft and white. **Veil:** Small, white, not fixed, often falling off. **Gills:** Closely crowded, free, white/pink/pink-red/black/inky. Turning to a liquid filled with spores.

Range: Nearly worldwide. **Ecology:** Disturbed habitats/lawns/meadows/roadsides/enriched soils/gardens/roads/trails. **Season:** Spring–early winter.

Edibility: Good, mild. Dipping in cold salt water or panfrying for a few minutes halts the self-liquefying process. Good pickled. 25–29% protein, 3% fat, 59% carbs, 3–7% fiber. **Medicinal:** Water extracts effective against breast cancer. Coprinin is a powerful antibiotic with potential to address bacteria that are resistant to pharmaceuticals. Lowers blood sugar in diabetics. Antifungal, helps with urinary tract infections, lung disease. In Traditional Chinese Medicine: known as *maotouguisan*, helps improve digestion, and treat hemorrhoids. **Dyes:** Iron pot=bayberry, ammonia=gray-green. **Remediation:** Kills nematodes. Uptakes mercury (27x), cadmium (8x), and arsenic

(21x). May be an arsenic indicator. **Other:** Can lift 3 inches of asphalt. Produces 5.25 billion spores in its life. A "foolproof" edible mushroom with no close look-alikes.

Cultivation: Will run on sawdust but fruits best on supplemented (faux) compost. Fruits well off of supplemented spent *Pleuortus* spawn and paper/pulp waste. Prefers dappled light outdoors.

C.17 – *Coprinus comatus* fruiting from gravel in Montreal.

Craterellus cornucopioides (L.) Pers.
Horn of Plenty, Death Trumpet

Spores: 8–11x5–7 µm, elliptical, smooth, whitish/buff/pale yellow. **Stalk:** 1–5x0.5–1.5 cm, with cap and tapering down, hollow except at base, tough, color like cap/underside. **Cap:** 2–10 cm broad, center hollow, margin folded back/wavy/split/lacerated, surface vicid, lightly scaly, grayish-black/dark brown/black, occasionally with yellowish margin, odor nice. Flesh thin, brittle, tough, colored like cap/paler. **Wrinkles:** Underside smooth/with deeply decurrent wrinkles. Colored like cap/paler/grayer.

Range: World wide in temperate regions. **Ecology:** Under conifers/hardwoods/shrubs (oak/holly/tan oak/manzanita/madrone/huckleberry). **Growth Habit:** Scattered/grouped. **Season:** Fall–spring.

Edibility: Edible, strong flavor, 50% protein dried. **Medicinal:** In homeopathy: helps integrate the shadow, stimulates first chakra. **Other:** It has been cultivated. The closely related and antitumor *C. fallax* is found in the summer and fall in eastern North America. It looks and tastes identical, but with a salmon/yellow underside.

C.18 – *Craterellus fallax*, a close relative of *C. cornucopioides*.

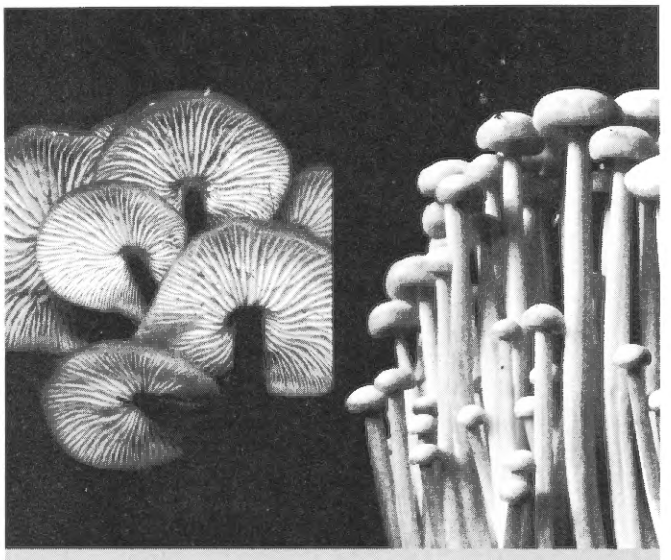
Flammulina velutipes (Curtis) Singer
Enoki, Velvet Foot, Winter Mushroom, Japan: *Enokitake, Nametake*

Spores: 6.5–9x35 µm, elliptical, smooth, not amyloid, white. **Stalk:** 2–11 cm long, 0.3–12 mm thick, equal/thicker below, slender, tough, slightly acentral, smooth, pallid/yellowish/orange/brown/rusty brown/blackish-brown, velvety with hairs that grow from the base upward. **Cap:** 1–10 cm broad, convex/plane/umbonate, smooth, slimy/viscid, reddish-brown/yellow-brown/yellow-orange/orange-brown/tawny, margin often paler/yellower. Flesh thin, white/yellowish. **Gills:** Adnate/adnexed/notched, white/pale yellow, close, with cystidia.

Range: Worldwide, sea level to tree line, throughout temperate regions, Europe, North Africa, Asia, North America. **Ecology:** Dead wood, mainly stumps/roots/tree wounds of living hardwoods/conifers (elm/aspen/poplar/willow/hackberry/mulberry/persimmon). **Growth Habit:** Dense clusters. **Season:** Late fall–winter.

Edibility: Yes—mild, sticky skin should be removed before cooking, 17–31% protein, 1.9–5.8% fat, 3.7% fat, 7.4% ash, rich in vitamin B3. Good in soups and sauces. Looks similar to the Deadly Galerina—confirm ID. **Medicinal:** Immune boosting, anticancer (lymphoma, prostate), potential for dementia, alzheimers, and heart diseases. May prevent or even cure gastroenteric ulcers and liver disease. Antiviral, cholesterol reducing, anti-inflammaroty, reduces immune response to food allergies. Flammulin (FVP), a water soluble polysaccharide, is highly effective against Ehrlich carcinoma and sarcoma 180. **Other:** One of the few winter mushrooms. Can freeze, thaw, and continue to grow.

Cultivation: Easy and quick. Fruits well on plain, pasteurized sawdust. Often grown in collared bottles to create high CO_2/lowlight conditions that encourage long stalks and pale caps. Some strains grow on Douglas-fir. Does well on stumps and logs, but should not be confused for *Galerina* or *Conocybe spp.*



C.19 – The wild (left) and cultivated (right) forms of *Flammulina velutipes*.

GALERINA MARGINATA (Batsch) Kühner
Deadly *Galerina*

SPORES: 8–11x5–6.5 µm, elliptical, roughened, rusty brown. **STALK:** 2–10x3–10 cm, equal/thicker below, pallid/brownish, darker below in age, dry, hollow, fibrillose below veil, white mycelial strands common at base. **CAP:** 1–6.5 cm broad, convex/plane/umbonate, smooth, viscid when moist, margin translucent and striate when moist, dark brown/yellow-brown/tan/yellowish, flesh thin, brown, odor mild/slightly farinaceous. **VEIL:** White, membranous/fibrillose, often forming a thin ring on stalk. **GILLS:** Attached/adnexed/slightly decurrent/seceding, close, yellowish/light brown/rusty-brown.

ECOLOGY: On rotting hardwood/conifers. **GROWTH HABIT:** Scattered/gregarious/in tufts. **SEASON:** Fall–spring.

EDIBILITY: Deadly poisonous! Contains amatoxins. Often confused with other LBMS, including *Psilocybes*. **OTHER:** *G. autumnalis* is a synonym.

C.20 – *Galerina marginata*, a deadly LBM.

GOMPHIDIUS GLUTINOSUS (Schaeff.) Fr.
Slimy Spike Cap

SPORES: 17–20x5.5–6 µm, spindle-shaped, brownish-black. **STALK:** 3.5–10x1–2 cm, white/greyish, often yellowish at base, minimal taste or smell. **CAP:** 12 cm broad, margin inrolled, convex/plane, grayish/brown. **VEIL:** Slimy/sticky, leaves indistinct ring. **GILLS:** Widely spaced, decurrent, waxy, hairy from cystidia, occasionally branched, white/gray/black.

RANGE: Europe, North America, Asia, Mexico. **ECOLOGY:** Associated with conifers (spruce/fir/Douglas-fir). **SEASON:** June–Nov.

EDIBILITY: Edible, but sliminess is unappealing. **MEDICINAL:** In China it is said to cure neurodermatitis. Contains 11 volatile monoterpenes. **REMEDIATION:** Cesium ≤10,000x. **OTHER:** Most widely spread *Gomphidius*.

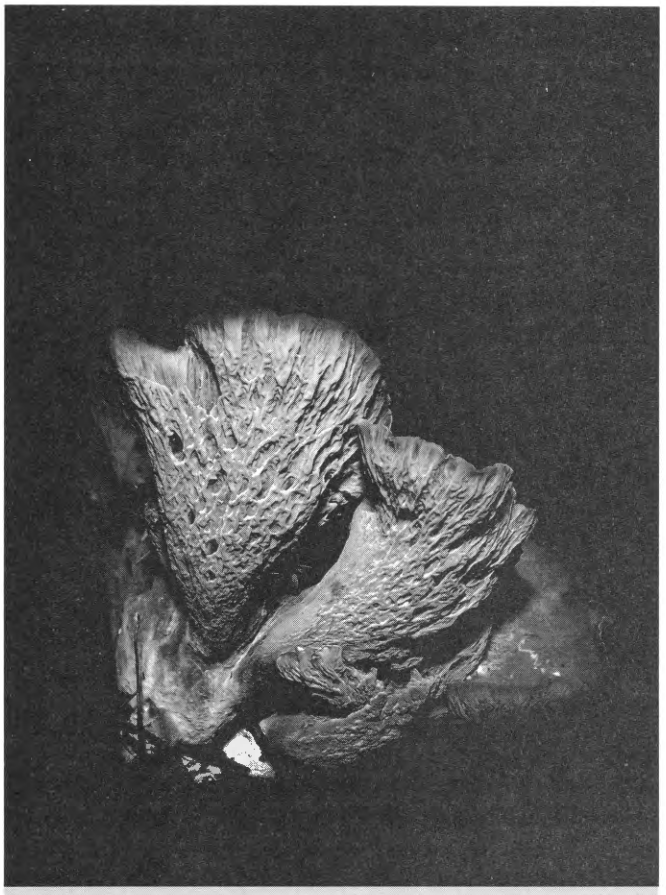
C.21 – *Gomphidius glutinosus* proudly displaying its slimy cap.

GOMPHUS CLAVATUS (Pers.) Gray
Pig's Ear, Clustered Chanterelle, Violet Chanterelle

SPORES: 10–13x4–6.5 µm, elliptical, slightly warty, yellow/orange-yellow. **STALK:** 3–10x1–3 cm, continuous with cap, equal/narrowed at base, central/off center, buff/pale purple often fused below, frequently curved, solid, firm. **CAP:** 2–15 cm broad, plane/depressed/uplifted, margin wavy/lobed, moist/dry, not viscid, smooth/with minute scales, light purplish/purplish-tan/olive-brown/tan/yellowish-buff, odor mild, flesh thick, firm, white/buff. **GILLS:** Shallow, deeply decurrent, blunt, forking veins/wrinkles, dull purple/purplish-tan/tan.

RANGE: North America, Austria, China, Czech Republic, France, Germany, Greece, Italy, Japan, Lithuania, Korea, Mexico, Pakistan, Poland, Romania, Russia, Sweden, Switzerland, Turkey. **ECOLOGY:** Under conifers/spruces/firs, preferring deep litter and moist, shady areas. **GROWTH HABIT:** Growing in fused/compound clusters. **SEASON:** Aug.–Oct.

Edibility: Yes—good pickled, often infested with bugs. **Medicinal:** Antifungal, anticancer, antioxidant. **Dyes:** Iron=purple/violet/lavender. **Other:** Endangered in Hungary. Legal protection provided in Slovakia.



C.22 – *Gomphus clavatus*, the Pig's Ear Mushroom.

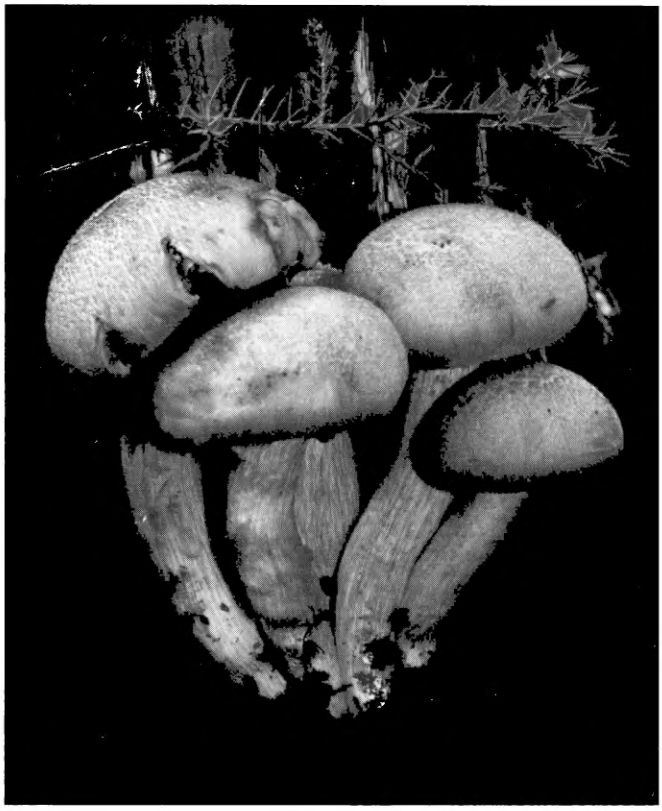
Gymnopilus junonius (Fr.) P.D. Orton

Laughing Gym, Laughing Cap, Laughing Jim, Spectacular Rustgill

Spores: 7–10x4.5–6 µm, with tiny warts, +/- elliptical, dextrinoid, bright rusty orange. **Stalk:** 3–20x1–6 cm, +/- equal/swollen in the middle, silky near apex, with orangeish/brownish ring zone or ring that collects spores, covered with fibers below ring, smooth by maturity, rusty orange/yellowish. **Cap:** 5-40 cm, convex/broadly convex/flat, dry, silky/with tiny fibers/scales, orange/brownish-orange, margin inrolled when young, KOH red then black. Flesh thick, firm, yellowish. **Gill:** Attached/slightly decurrent, close, yellowish/orangeish/orange-brown.

Range: Asia, USA, Europe. **Ecology:** Saprobic on hardwoods/conifer stumps/logs. Lowland woods near rivers. **Growth Habit:** In clusters/alone. **Season:** Summer–fall.

Edibility: Psychoactive. Very bitter. **Medicinal:** Anticancer.



C.23 – *Gymnopilus junonius*, a psychoactive mushroom.

Hydnum repandum L.

Hedgehog, Sweet Tooth, Wood Hedgehog, Pig's Trotter, China: *Chijun*, Czech: *Houby Losákovité*, Dutch: *Gele Stekelzwam*, Finnish: *Suomenorakas* (*H. umbilicatum*), French: *Pied de Mouton*, German: *Semmelstoppelpilz*, Italian: *Steccherino Dorato, Gallinaccio Spinoso*, Polish: *Kolczakowate*, Russian: *Gidnoom, Yezhevik Zholty*, Spanish: *Hongos Con Púas*, Swedish: *Blek Taggsvamp*

Spores: 6.5–9x5.5–8 µm, broadly elliptical/round, smooth, white. **Stalk:** 3–10x1–5 cm, central/off center, equal/tapered in either direction, firm, white/like cap, bruising ochre/orange-brown, base smooth/downy. **Cap:** 1–25 cm broad, convex/plane/depressed, margin inrolled/wavy, dry, +/- smooth, flesh color/pale orange/orange-tan/salmon/pale cinnamon/reddish-tawny, bruised areas dark orange, odor mild, taste mild/bitter/peppery. Flesh white, thick, firm, brittle, often bruising yellow/orange-brown. **Teeth:** 2–7 mm, white/yellowish/salmon-buff, bruising dark orange, slender, brittle, soft, often decurrent.

Range: North America, Asia, Australia, Europe, Mexico, Canada. **Ecology:** On ground under hardwoods/conifers (oak/birch/beech). **Growth Habit:** Solitary/scattered. **Season:** July–Nov.

Edibility: Choice, sweet/nutty, crunchy, tannic in age. **Medicinal:** Mild antibiotic activity, anticancer, anti-inflammatory, lowers blood cholesterol levels in animals.

C.24 – *Hydnum repandum*, a toothed cap and stalk mushroom.

Hypholoma capnoides (Fr.) P. Kumm.
Conifer Tuft, Smoky Gilled Clustered Woodlover

Spores: 6–7.5x3.5–4.5 µm, elliptical, smooth, purple-brown/dark purple-gray. **Stalk:** 5–10 cm x 3–10 mm, equal/tapering down, yellow above, darker yellow below. **Cap:** 2–7 cm, convex/umbonate/plane, surface smooth, yellow/cinnamon, thin flesh, mild taste. **Veil:** Occasionally leaving some remnants. **Gills:** Adnate/seceding, close, pale gray/dark gray/purple-brown, chryosocystidia on gill face.

Range: Throughout North America and temperate parts of Europe. **Ecology:** Conifer log/stump lover, especially Douglas-fir. **Season:** Spring–first frost.

Edibility: Nutty, good in stir-frys. **Medicinal:** Antibacterial, anticancer (breast, prostate). Helps with tuberculosis (TB). **Remediation:** Accumulates aluminum. Research is limited.

Cultivation: Does well on plain sawdust in bags, bottles, or trays. Prolific and persistent on stumps. Some strains can be grown on redwoods and cedars! The closely related *H. sublateritium* (Brick Cap) grows well on hardwoods.

C.25 – *Hypholoma capnoides* is easy to recognize once it's familiar.

Hypholoma fasiculare (Huds.) P. Kumm.
Sulfur Tuft

Spores: 6–8x3.5–5 µm, elliptical, smooth, purple-brown/deep purple-gray. **Stalk:** 5–12 cm x 3–15 mm, equal/tapering down, yellow/tawny, often with rusty brownish stains from base up, often curved/sinuous, dry, firm. **Cap:** 2–9 cm broad/broadly conical/bell-shaped/ convex/broadly umbonate/plane, smooth, not viscid, bright sulfur/greenish-yellow/yellow-orange, center sometimes darker, margin often hung with veil remnants, taste bitter. Flesh thin, yellow. **Veil:** Thin, pale yellow, evanescent/leaving small pieces on cap margin/and fibrillose zone on stalk that is later blackened by falling spores. **Gills:** Adnate/seceding, close, sulfur yellow/greenish-yellow/olive/purple-brown/black, chrysocystidia present on faces.

Range: Europe, Asia, North America. **Ecology:** Decaying hardwood/conifers, sometimes buried wood/roots. **Growth Habit:** Tufts or dense clusters. **Season:** Spring–first frost.

Edibility: Poisonous, can take up to 10 hours to show. **Medicinal:** Anticancer (breast, prostate), tuberculosis. In homeopathy: for spiritual quest, to integrate wisdom, nervous conditions, skin, nausea, digestion issues. **Dyes:** Alum=nice yellow. **Other:** Similar in appearance to *H. capnoides*, except for distinct yellow-green gills. Fluoresces under UV light.

Hypsizygus ulmarius (Bull.) Redhead
Elm Oyster, Japanese: *Shirotamogitake*

Spores: 5–6 µm, smooth, roundish, inamyloid, white/buff. **Stalk:** 5–15x1–4 cm, dry, smooth/hairy, whitish, solid, off center/nearly central, odor mild. Flesh white. **Cap:** 5–28 cm, convex and slightly inrolled/flat/slightly sunken center, white/buff/tan, cracking, with/without small scales. **Gills:** Attached, not decurrent, whitish/cream.

Range: Temperate eastern North America, Europe, Japan. **Ecology:** Saprophyte on hardwoods (elm/box elder/cottonwood/beech/willow/maple/oak). **Growth Habit:** Alone/in pairs. **Season:** Sept.–Dec.

Edibility: Good, superior to all *Pleurotus* Oysters in flavor and texture. **Medicinal:** Immune boosting, antiallergenic, antifungal, antibacterial, anticancer (leukemia, colon, ovarian, prostate), antioxidant. Helps with sickle cell anemia. Helps in treating pre-cancer of esophagus. Hypsin, a heat-stable ribosome-inactivating protein, is antifungal and antiproliferative.

Cultivation: Aggressive, adaptive, fast, versatile. Commonly cultivated like *Pleurotus* species on straw. *H. tessulatus* is also cultivated. It is smaller, prefers wood, and has a rich, nutty flavor. Both do well outdoors on logs/stumps/wood chip beds.

C.26 – *Hypsizygus ulmarius* fruiting from a box elder in Illinois.

C.27 – *H. tessulatus*, a commonly cultivated relative of *H. ulmarius*.

LACCARIA LACCATA (Scop.) Cooke
Deceiver, Waxy *Laccaria*, Lackluster *Laccaria*

SPORES: 7–10 µm, subglobose/globose, with spines 1–2x1 µm, inamyloid, white. **STALK:** 2–10x0.5–1 cm equal/tapering down, smooth/finely hairy, may be longitudinally grooved, colored like cap, with white mycelium at base, becoming hollow. **CAP:** 1–4.5 cm, convex/flat/uplifted, often with central depression, margin smooth and even/lined/grooved, bald/finely hairy, orangeish-brown/buff, color changing as it dries out. Flesh thin, colored like cap. **GILLS:** Attached/decurrent, distant/close, pinkish/purplish.

RANGE: North America, Europe, Mexico, Costa Rica. **ECOLOGY:** Mycorrhizal with hardwoods/conifers (pine/beech/birch). **GROWTH HABIT:** Scattered/densely gregarious. **SEASON:** Spring–fall.

EDIBILITY: Yes—mild/radishlike. **MEDICINAL:** Anticancer. **OTHER:** Widespread, common. Can be tricky to identify.

CULTIVATION: One of the few ectomycorrhizal species that can be easily and consistantly cultivated with trees, see Chapter 9.

C.28 – *Laccaria laccata* is edible and medicinal.

LACTARIUS RUBIDUS (Hesler & A.H. Sm.) Methven
Candy Cap, Curry Milkcap

SPORES: 6–8 µm; round; amyloid warts and connectors forming partial reticula that is 0.5–1.0 µm high, pale yellow/whitish. **STALK:** 2–7x0.5–1.5 cm thick, colored like the cap/paler; +/- less equal, smooth, without pot-holes, often with orangeish fuzz at the base. **CAP:** 2–8 cm, convex/flat/shallowly vase-shaped, dry/sticky, slightly wrinkled/uneven, reddish-brown/orangeish-brown, KOH negative. Flesh pale orange, not staining when sliced. Latex watery/whey-like, not copious, not staining tissues. **GILL:** Attached/slightly decurrent, close/nearly distant, pale orange, developing cinnamon stains, not staining from latex.

RANGE: North America, Europe. **ECOLOGY:** Mycorrhizal with oaks (coastal live oak/tanoak)/Douglas-fir, on humus/moss, along trails/road banks. **GROWTH HABIT:** Alone/scattered/gregariously/in loose clusters. **SEASON:** Late fall–early spring.

EDIBILITY: Yes—mild and good. Odor like maple syrup/burned sugar, becoming stronger when the mushroom is dried. Excellent in baked goods.

MEDICINAL: Anticancer, antibacterial. **OTHER:** *L. camphoratus* and *L. fragilis* are closely related. The sweet odor persists for a very long time.

LACTARIUS RUFUS (Scop.) Fr.
Red Hot Milk Cap

SPORES: 7.5–11x5–7.5 µm, elliptical, amyloid warts/ridges, pale yellow. **STALK:** 4–11x1–15 cm, equal, rigid, fragile, stuffed/hollow. **CAP:** 4–12 cm broad, convex/plane/depressed, dark reddish, rather fragile, not viscid, smooth, odor mild, latex white and not changing, delayed spicy taste. **GILLS:** Adnate/slightly decurrent, Pale/reddish, exuding white latex when broken, crowded.

RANGE: North America, Europe. **ECOLOGY:** Conifers/pine/spruce/birch. **SEASON:** Late summer–early winter.

Edibility: Not recommended, may be poisonous. Commercially canned in Scandinavia. If desired, cook for at least 10 minutes in water. Can be preserved in vinegar or salt water or frozen then lightly salted. **Medicinal:** Anticancer, antibacterial, antifungal. **Other:** The most acrid of all mushrooms.

C.29 – *Lactarius rufus.*

Lentinula edodes (Berk.) Pegler

Shiitake, Black Mushroom, Sawtooth Oak Mushroom, Chinese: *Shanku, Zhau Gu, Mo-Ehr, Dongo,* Czech: *Sii-take,* French: *Lentin, Cortinaire de Berkeley,* German: *Shiitakepilz,* Japanese: *Koshin, Donko, Danko,* Polish: *Lyczak Shii-take,* Russian: *Greeb-shiitakye,* Spanish: *Hongo Shii-take*

Spores: 5–6.5x3–3.5 µm, ovoid/oblong/ellipsoid, white, **Stalk:** Fibrous, tough. **Cap:** 5–25 cm, convex/plane, black/dark brown/light brown/tan. **Veil:** Absent. **Gills:** White, brown if damaged, serrated in age.

Range: Originally only known to Japan, China, and Korea, now naturalizing in the U.S. **Ecology:** Saprophyte on hardwood, producing a mottled white rot. **Season:** Spring–fall.

Edibility: Delicious, 13–18 % protein, 6–15% fiber, 2–5% fat, niacin, thiamin, riboflavin. Great baked, grilled, or sautéed in tamari and sesame oil. **Medicinal:** Thoroughly researched, highly regarded. See Chapter 7. **Remediation:** Well researched. Effective against PAHs, PCBs, and PCPs, and various dyes.

Cultivation: Much written on the topic. Forms a unique brown crust after going through a bumpy, "popcorn" stage. Once crusted, can be removed from bag and dunked. Does great on logs (oak/sweetgum/poplar/cottonwood/eucalyptus/alder/ironwood/beech/birch/willow/other hardwoods [but no fruitwoods]). Different strains fruit at different temperature ranges (warm, cold, wide-range). Example fruiting formulas:

Sawdust – 78%
Rice/wheat bran – 16%
Sugar – 1.5%
Corn flour – 1.7%
Gypsum – 2%

Sawdust – 64%
Spent coffee grounds – 20%
Wheat bran – 15%
Gypsum/lime – 1%

Sawdust – 78%
Wheat bran – 20%
Calcium carbonate – 1%
Sucrose – 1%

Sawdust – 82%
Wheat bran – 16%,
Gypsum – 1.4%
Potassium phosphate, dibasic – 0.2%
Lime – 0.4%

Sawdust – 54%
Spent coffee grounds – 30%
Wheat bran – 15%
Gypsum – 1%

Sawdust – 63%
Corncob powder – 20%
Wheat bran – 15%
Calcium superphosphate – 1%
Gypsum – 1%

Sawdust – 76%
Wheat bran – 18%
Corn powder – 2%
Gypsum – 2%
Sugar – 1.2%
Calcium superphosphate – 0.5%
Urea – 0.3%

Lyophyllum decastes (Fr.) Singer

Fried Chicken, Japanese: *Hatakeshimeji*

Spores: 4–6 µm, round, smooth, white. **Stalk:** 3–15x0.5–2.5 cm, solid, equal/tapering down, often curved, smooth, dry, white/brown. **Cap:** 3–12 cm broad, convex/plane/slightly uplifted, smooth, not viscid, odor mild, dark brown/grayish-brown/yellowish-brown, margin usually lobed. Flesh firm, white. **Gills:** Adnate/slightly decurrent, usually notched, close, white/pale yellowish.

Range: Europe, North America west coast from Alaska to California. **Ecology:** Parks/garden soil/grassy areas/waste areas/urban areas/roadsides. **Growth Habit:** In dense clusters. **Season:** Summer–fall.

Edibility: Edible, mild flavor, some people are mildly allergic. **Medicinal:** Anticancer, antiallergy, antidiabetic, antifungal, anti-inflammatory, antitumor, lowers cholesterol.

Cultivation: LC recipe: 3% glucose 1% yeast.

C.30 – *Lyophyllum decastes.*

Macrocybe titans

(H.E. Bigelow & Kimbr.) Pegler, Lodge & Nakasone

Spores: 5.5–7x4–5 µm, smooth, broadly ellipsoid/nearly round, inamyloid, creamy. **Stalk:** 6–35x5–13 cm thick, equal/slightly swollen below, dry, whitish, often with small brownish/whitish scales. **Cap:** 8–100 cm(!), convex/broadly convex/flat, dry, smooth/cracking in age, pale yellowish/brownish/buff/pale cinnamon/yellowish center, margin inrolled. Flesh white, firm, not staining. **Gills:** Attached, crowded, white/grayish/pale brown.

Range: Mexico, Central America and Northern Florida, North America, common in Florida. **Ecology:** Saprobic in grassy/sandy areas, disturbed ground, from active *Atta* ant colonies. **Growth Habit:** Alone/gregarious/in clusters. **Season:** Fall–winter.

Edibility: Edible. **Other:** This massive mushroom is likely the largest agaric in North America. *Tricholoma titans* is a synonym.

C.31 – *Macrocybe titans*, a legendary massive mushroom.

Macrolepiota procera (Scop.) Singer

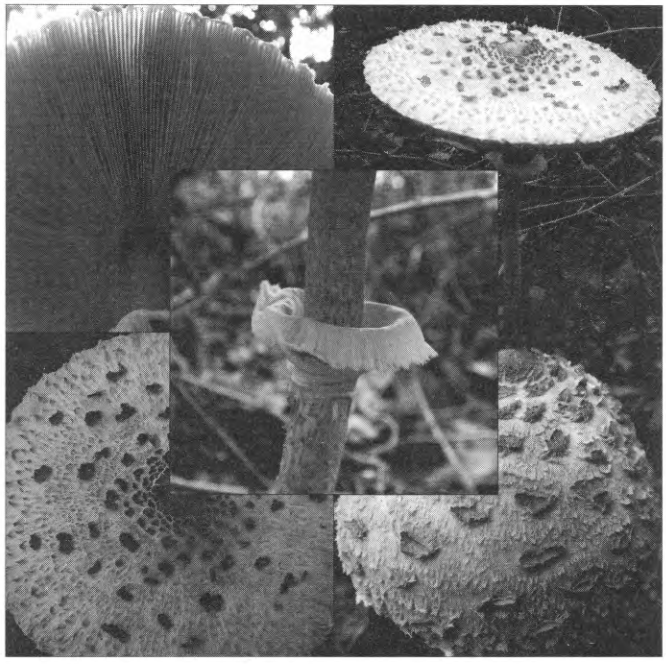
Shaggy Parosol

Spores: 12–18x8–12 µm, broadly elliptical, thick-walled, with apical pore, smooth, dextrinoid, whitish/pinkish. **Stalk:** 12–40x0.8–1.5 cm, long and slender, enlarged base, pale, lower surface with small brown scales that wear away in age. **Cap:** 7–25+ cm broad, oval/convex/plane/umbonate, dry, smooth and brown at first, becoming covered in brown scales and patches but retaining a smooth and dark umbo, flesh between scales white/buff/grayish/brownish. Inner flesh soft and white/reddish. **Veil:** Membranous, leaving a thick, white and brown, double-edged ring high on stalk that is movable. **Gills:** Free, broad, close, white/pinkish/tan/brownish.

Range: Widely spread in temperate lowlands of Europe, North America, New England and the South, Mexico, Southern California, Europe. **Ecology:** Old pastures/trails/yards/gardens/woods. Prefers dappled sun with minimal understory. Associated with conifers/aspens/oaks. **Growth Habit:** Solitary/widely scattered/small groups. **Season:** Sept.–Dec.

Edibility: Choice—strong, meaty, nutty flavor. High in 8 essential amino acids. **Remediation:** Accumulates mercury 230x, copper, zinc, rubidium, selenium, and cobalt.

Cultivation: Naturalizes outdoors in plant debris.



C.32 – The key distinguishing features of *Macrolepiota procera*.

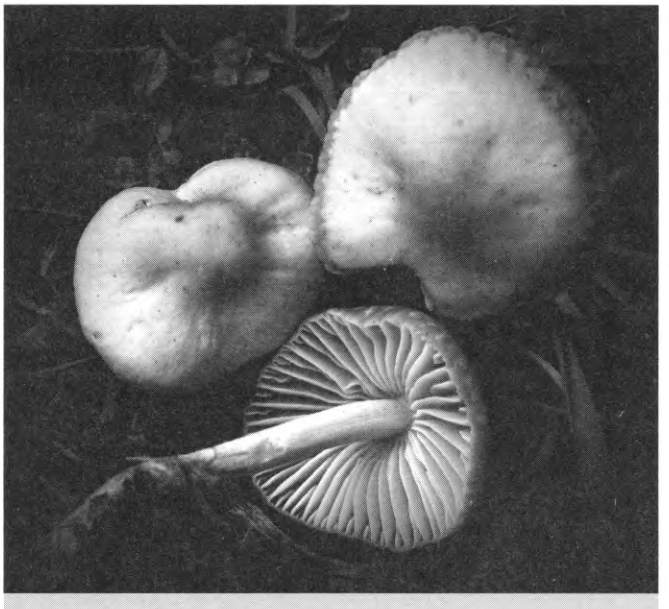
Marasmius oreades (Bolton) Fr.

Fairy Ring Mushroom, Scotch Bonnet, Blackfoot (Alberta): *Kok-a-tos-i-u*, Basque: *Xapo-por-retxiko* (Toad Mushroom), Czech: *Obecná, Spicka*, Dutch: *Weidekringzwam* French: *Marasme, Faux Mousseron*, German: *Nelkenschwindling*, Italian: *Gambe Secche*, Polish: *Twardzeoszek*, Russian: *Nyegniyuchnik*, Spanish: *Ninfa*, Swedish: *Nejlik-broskskivling*

Spores: 7–10x4–6 µm, elliptical/irregular, apiculate, smooth, not amyloid, white. **Stalk:** 2–8x1.5–6 cm, equal/tapering down, tough, pliant, smooth, colored like cap/paler. **Cap:** 1–6 cm broad, bell shaped/umbonate/convex/plane, often with broad umbo, margin faintly striate when moist and usually uplifted in age, smooth, dry, tan/light brown, odor nice. Flesh tough, pliant, pale, reviving when moistened. **Gills:** Adnate/adnexed/free, well-spaced, broad, white/tan/brownish.

Range: Pacific NW, California, Europe. **Ecology:** Lawns/parks/cemeteries/meadows/roadsides. **Growth Habit:** Often forming rings. **Season:** May–Oct.

Edibility: Good. **Medicinal:** Dew used for complexion. Antimicrobial, antifungal, anticancer, antihypertensive, anti-inflammatory. A nerve tonic, specified for leprous neuralgia, sciatica, trigeminal neuralgia, and migraine headaches. Helps with rheumatic joint pain. Steam distillation yields 0.2% oil. **Remediation:** Activity demonstrated against TNT and PAHs (e.g. benzo[a]pyrene [95%]). **Other:** One of the largest fairy rings reportedly encircles Stonehenge and is over 1,000 years old. Rings grow 12–13 cm/year.



C.33 – *Marasmius oreades.*

Neolentinus lepideus (Fr.)

Train Wrecker

Spores: 9–12x4–5 µm, cylindrical, smooth, not amyloid, whitish. **Stalk:** 3–5x1–3 cm, central/off center, tapered down, tough, colored like cap, with brown scales/fibrils below. **Cap:** 5–20 cm broad, convex/plane, whitish/pale yellow/darker brownish, with scales, dry/slightly viscid, odor pungent/fragrant. Flesh thick, white, bruising yellow. **Veil:** Membranous, forming a pale annulus high on stalk that may disappear. **Gills:** Usually decurrent, occasionally notched/adnate, whitish/buff/yellowish, usually bruising brownish, edges entire/serrated.

Range: North America. **Ecology:** Brown rotter on conifers/pines/lumber. **Season:** May–Sept.

Edibility: Caps good when thoroughly cooked. **Medicinal:** Anticancer, immunomodulator, antibacterial, antifungal. Contains 43 essential oil compounds. **Other:** Sometimes found on railroad ties, causing derailment.

Omphalotus olivascens

H.E. Bigelow, O.K. Mill. & Thiers

Jack-O Lantern

Spores: 6–8x5.5–7 µm, elliptical/round, smooth, white/yellowish. **Stalk:** 4–20x1–8 cm, central/off center, equal/tapered down, solid, dry, colored like cap/gills. **Cap:** 4–25 cm broad, convex/plane/depressed, smooth, not viscid, golden yellow/orange-olive/dull orange/brownish-orange/olive, odor mild. Flesh thin, colored like cap. **Gills:** Decurrent, close, olive/bright yellow-orange, luminescent when fresh.

Range: West coast. Europe, North America, Central America, Asia. **Ecology:** Around hardwood trunks/stumps/buried wood (oak/manzanzanita/madrone/chinquapin). **Growth Habit:** In clusters. **Season:** Fall–spring.

Edibility: Poisonous. **Medicinal:** Anticancer (ovary, prostate, liver, breast, lung, colon), antifungal, antibiotic. **Dye:** Various. Iron=dark green, alum=purple, no mordant=lavender.

Panellus stipticus (Bull.) P. Karst.

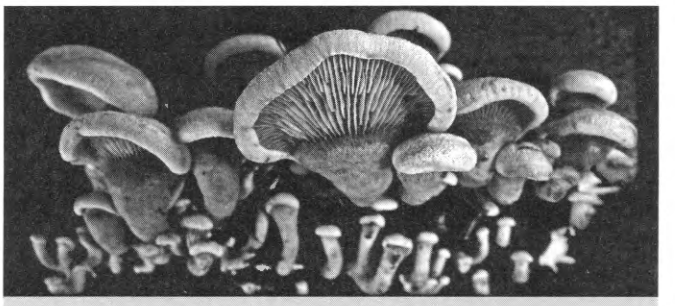
Late Fall Oyster, Bitter Oyster

Spores: 3–5x1.5–3 µm, elliptical/oblong/sausage-shaped, smooth, amyloid, white. **Stalk:** 0.5–2 cm long, 3–8 mm thick, off center/lateral, base often narrow, usually flatish, cap color/paler. **Cap:** 0.5-3 cm broad, fan-/kidney-shaped, convex/plane/depressed near stalk, dry, slightly hairy, buff/ochre/tan-brownish/cinnamon-brown, sometimes zoned, taste acrid/astringent. Flesh thin, tough, white/yellowish, KOH negative on surface. **Veil:** Absent. **Gills:** Adnate/decurrent, close, narrow, often forked, brownish/pale cinnamon/ochre/buff, often luminescent.

Range: North America, Asia, Australia, Europe. **Ecology:** Broadleaf deadwood (oak/beech/birch/maple/hickory/hornbeam/alder/hazel/ash/pine). **Season:** Year-round.

Edibility: Too small, tough, and bitter to eat. **Medicinal:** A styptic (blood thickener), antibacterial, anticancer.

Cultivation: Glow-in-the-dark mycelium (and fruit bodies) can be easily cultivated. Acidifying substrates to a pH of 4 increases luminescence.



C.34 – *Panellus stipticus*, a glow-in-the-dark mushroom.

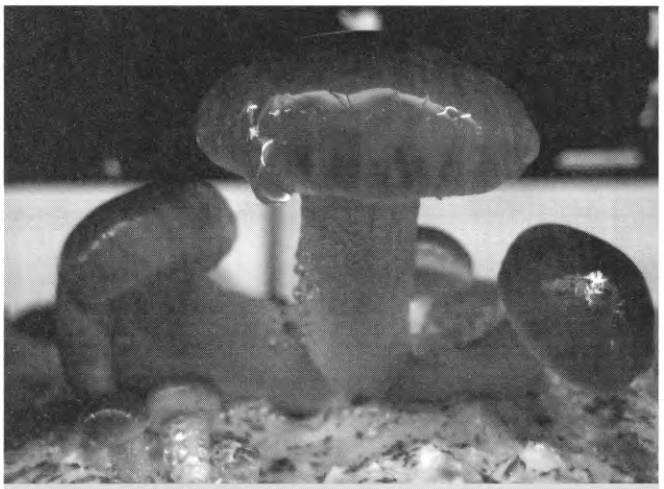
PHOLIOTA NAMEKO (T. Itô) S. Ito & S. Imai
Nameko, Butterscotch mushroom

SPORES: Brown/cinnamon-brown/rusty-brown. **STALK:** 5–7 cm, with a yellow annulus on upper part. **CAP:** 5–8 cm, smooth with slimy coating. **GILLS:** Attached, not decurrent, white/yellow/rust/ochre.

RANGE: Highlands of China and Taiwan, not known in Europe or North America. **ECOLOGY:** Hardwood stumps/logs (oak/beech/chestnut/maple). **GROWTH HABIT:** Large clusters. **SEASON:** Spring–fall.

EDIBILITY: Choice. Common in traditional miso soup recipes. 20.8% protein, 4.2% fat, 66.7% carbs, 6.3% fat, thiamin, riboflavin, niacin, calcium, potassium, iron, sodium. Slime on cap disappears upon cooking. **MEDICINAL:** Anticancer, anti-inflammatory.

CULTIVATION: Easy and common. Substantial fruitings possible on conifer sawdust with 15% bran. To initiate orange slime layer formation, increase light, mist frequently, and lower temperature and CO_2. Casing helpful, but adds dirt to sticky cap. To encourage second flush, rough the casing surface. Good for hardwood stumps/logs (beech/poplar/alder/aspen/oak/eucalyptus/maple/beech/poplar) that are partially buried.



C.35 – *Pholiota nameko* is commonly cultivated in Asia.

PLEUROTUS OSTREATUS (Jacq.) P. Kumm. *& ALLIES*
Pearl Oyster, Japanese: *Hiratake, Tamogitake,* Chinese: *Hao Gu,* Czech: *Hlíva,* Dutch: *Oesterzwam,* Finnish: *Vinoka,* French: *Oreillette, Couvrosse, Pleurote en Huître,* German: *Austernseitling,* Italian: *Orecchione Gelone, Agarico Ostreato,* Polish: *Boczniak Ostrygowaty,* Russian: *Vyeshyenka Obiknovyennaya,* Spanish: *Pleuroto Ostreado,* Swedish: *Ostronskivling*

SPORES: 8–9x3–4 µm, oblong/elliptical, smooth, not amyloid, white. **STALK:** 0.5–5x1–2 cm, stout, off center/lateral, solid, firm, dry, hairy/downy at base. **CAP:** 4–20 cm, oyster/fan-shaped, convex/plane/funnel-shaped, smooth, slightly lubricous if moist, not viscid, white/bluish-gray/grayish-brown/tan/dark brown/yellowish, often wavy/lobed, odor and taste mild. Flesh firm, white, soft. **VEIL:** Absent. **GILLS:** Decurrent (if stalk is present), close, broad, white/grayish/yellowish.

RANGE: Worldwide in temperate zones, North America, Asia, Australia, Europe. **ECOLOGY:** Low valleys, on hardwood logs/stumps (elm/willow/aspen/beech/cottonwood/alder/sycamore/oak/tanoak), rarely on conifers. **GROWTH HABIT:** Usually in shelving and overlapping rows/columns. **SEASON:** Spring and late fall.

EDIBILITY: Yes—mild and delicious, 10–30% protein, vit. C, niacin, folic acid, potassium. Check gills for insects. **MEDICINAL:** Produces lovastatin (concentrated in spores>gills>cap), which helps lower cholesterol. Antibacterial, strengthens veins and relaxes tendons, effective in the treatment of lumbago, numbed limbs, and blood vessel discomfort, antitumor, nerve tonic, antioxidant, anti-inflammatory, antiviral (HIV, common flu, hepatitis C), antacid properties. One of its glucans is the anticancer pleuran. **DYES:** Ammonia+iron pot=gray-green. **REMEDIATION:** Heavily researched, highly regarded. Exuded metabolites are a nematode tranquilizer. Effective against many aromatic compounds (e.g. petroleum products, benzopyrenes, nerve agents, dioxins, PAHs, PCBs, TNT). Concentrates cadmium and mercury (65–140x). Potentially able to create a type of fuel. **OTHER:** Its prolific spore load causes allergic reactions in some people.

CULTIVATION: The go-to beginner mushroom. Adaptive, tolerant of stress/competitors, wide-ranging appetite (grows on 200+ waste streams). Does well on stumps and partially buried logs. Grows well on straight straw as well as with supplementation. The closely related *P. pulmonarius* (Phoenix Oyster) prefers warmer temperatures and some strains can grow on conifers—it is very fast growing and tenacious. The colorful Pink Oyster (*P. djamor*) and Golden Oyster (*P. citrinopileatus*) are very quick growing and prefer warmer temperatures. The King Oyster (*P. eryngii*) is much more robust and meaty—it is commonly cultivated in sets of two fruit bodies from nutrified sawdust in bottles. Example fruiting formulas for *P. ostreatus:*

Cotton seed hulls – 97%
Gypsum – 2%
Lime – 1%

Water hyacinth – 80%
Cereal straw – 17%
Gypsum – 2%
Lime – 1%

Rice straw – 80%
Cotton waste – 18%
Gypsum – 1%
Lime – 1%

C.36 – *Pleurotus ostreatus.* Big, fleshy, delicious.

PSILOCYBE CUBENSIS (Earle) Singer

Blue Meanies, Boomers, Caps, Cubes, God's Flesh, Gold Cap, Golden Tops, Liberty Caps, Little Smoke, Magic Mushrooms, Musk, Shrooms, Silly Cybin, Silly Putty, Simple Simon

Spores: 1.5–17x8–11 µm, subellipsoid, dark purple brown. **Stalk**: 4–15x0.5–1.5 cm, white/yellowish, hollow/somewhat stuffed, with white membranous annulus, bruising blue/bluish-green. **Cap**: 2–8 cm, conic/convex/broadly convex/plane, may retain a slight umbo, margin even, reddish-cinnamon brown/golden brown, viscid when moist, hygrophanous, +/- smooth. Flesh whitish, bruising blue. **Gills**: Adnate/adnexed/seceding, close, narrow/slightly wider towards the center, pallid/gray/dark purplish/blackish, somewhat mottled, edges remaining whitish.

Range: Subtropical climates of SE Asia, India, Australia, the Americas. **Ecology:** Primarily on dung. **Growth Habit:** Solitary/in groups. **Season:** Summer.

Edibility: Moderately psychoactive.

Cultivation: The most commonly cultivated psychoactive mushroom in the world. Tolerable of many substrates and easy to grow. Dozens of strains in circulation, with names often reflecting their source of origin (Cambodian, Gulf Coast) or appearance (Albino, Penis Envy). Strategies include PF Tek (alkaloid levels can be increased 330% with the addition of 0.1 grams tryptamine HCL to 45 milliliters of water for each half-pint jar), cased grains in trays, grains to (supplemented) pasteurized straw, grains to (supplemented) pasteurized dung (cased once myceliated), and grains to pasteurized compost (cased once myceliated). Yields are best when some amount of poo is incorporated into the substrate. Monotubs and laundry baskets popular. Misting stopped once pins form. After harvest: holes in substrate are filled with casing, misting is increased. Grown outdoors under cloches in compost rows.

C.37 – Wild harvested *Psilocybe cubensis.*

PSILOCYBE CYANESCENS Wakef.

Caramel Caps, Blue Angels, Fantasi-takes, Wavy Caps

Spores: 9–12x5–8 µm, smooth, elliptical spores, dark purple brown. **Stalk:** 3–8x2–6 cm, dry, whitish, staining blue/blue-green, equal/slightly bulbous base. **Cap:** 1.5–5 cm, caramel/chestnut-brown when moist, fading to pale buff/slightly yellowish when dried, usually distinctly wavy at maturity, odor/taste farinaceous. **Veil:** Cobwebby, may leave an annular zone. **Gills:** Adnate, light/dark purple brown, with lighter edges.

Range: NW U.S., NE North America, British Isles, Eastern Europe, Southern Argentina, Northern Africa, New Zealand, temperate Australia, Asia. **Ecology:** Public buildings/flower gardens/coastal campgrounds. Rarely in natural settings. **Growth Habit:** Scattered/in troops. **Season:** Oct.–Feb.

Edibility: Potently psychoactive. **Remediation:** Nerve agents, PAHs. **Other:** Likely a large complex of species. Delineation is ongoing. Occasionally confused with the deadly *Galerina marginata.* Both have similar habits and appearances, and bear a superficial resemblance to each other.

Cultivation: Aggressive on plain sawdust (alder/cottonwood/oak/birch/beech/Douglas-fir), naturalizes readily, fruits best in wood chip beds outdoors. Requires an extended cold period to initiate fruiting. Indoor fruitings produce low yields. Outdoor patches may take 2 years to fruit and only fruit for 1-3 seasons. *P. azurescens* is a coastal species that is cultivated. *P. allenii* is cultivated like *P. cyanescens.* All 3 species prefer a grass layer.

C.38 – A wild patch of *Psilocybe cyanescens.*

PSILOCYBE MEXICANA R. Heim

Chinantec: *A-mo-kid*, Spanish: *Angelito* (Little Angel), *Chamaquillo* (Little Boy), *Pajarito* (Little Bird), Mixe: *Atka:t*, *Kongk*, *Pi-tpa*, *Nashwinmush* (Earth Mushroom or World Mushroom), Catino: *Cui-ya-jo-to-ki*, Mazatec: *Di-chi-to-nize*, *Ndi-shi-tjo-ni-se*, *Nize* (Little Bird), Zapotec: *Mbey-san*, Aztec: *Teonanacatl*, Nahuatl: *Teotlaquilnanacatl*

SPORES: 8–12x5–8 µm, ovoid, smooth, dark purple-brown. **STALK:** 4–10 cm x 1–3 mm, equal, hollow, straw color/brownish/reddish-brown, annulus absent. **CAP:** 0.5–3 cm, conic/campanulate/subumbonate, often with a slight papilla, hygrophanous/glabrescent, margin even/striate, ocherous/brown/beige/straw-color, sometimes with blueish/greenish tones, turning blue when injured. **GILLS:** Adnate/adnexed, gray/purple-brown, edges whitish.

RANGE: Mexico, Central America, North America, Costa Rica, Guatemala. **ECOLOGY:** Among moss along roadsides, trails, humid meadows, cornfields, grassy areas bordering deciduous forests. Common at 980–1,800 feet (300–550 m). **GROWTH HABIT:** Solitary/in small groups. **SEASON:** May–Oct.

EDIBILITY: Psychoactive. **Other:** One of the primary mushroom species worked with by Maria Sabina. The species from which psiloc(yb)in was first isolated.

CULTIVATION: Psychoactive sclerotia ("philosopher's stones") often grown in jars of rye grass seed or white rice, thereby avoiding bulk substrates, casing layers, and fruiting environments. Shaking of grains is stopped when sclerotia begin to form and continue developing over 2–3 months. Dry, they are roughly two-thirds the potency of *P. cubenesis*, with a consistency similar to peanuts. Fresh, their potency is roughly twice that of *P. cubensis*. Fruits if a layer of sand and a casing layer is applied. *P. tampanensis* is grown in a similar fashion.

C.39 – *Psilocybe mexicana.*

RUSSULA XERAMPELINA (Schaeff.) Fr.

Shrimp Russula, Crab Brittlegill

SPORES: 8–11x6–8.5 µm, elliptical/round, with amyloid warts. **STALK:** 3–12x1–4 cm, equal/slightly enlarged base, usually longitudinally lined, dry, rose pink/white with a tinge of pink near base, staining yellowish then brown where scratched, brittle and snapping like chalk, deep green in ferrous sulfate. **CAP:** 5–30 cm broad, convex/plane/centrally depressed, smooth, viscid when moist, color variable: red/dark red/purple/brownish-olive, often with darker margin, striate and crablike scent in age. Flesh thick, white, bruising yellowish. **GILLS:** Close, adnate/adnexed, white/dull yellow, staining like flesh, drying brownish/grayish.

RANGE: North America, Europe, Costa Rica. **ECOLOGY:** Under Douglas-fir/alder/beech/oak/hemlock/pine. **GROWTH HABIT:** Solitary/gregarious. **SEASON:** Summer–late fall.

EDIBILITY: Good—crustacean-like scent in age or when dried. Taste mild. **MEDICINAL:** Antioxidant, lowers blood cholesterol, anti-inflammatory, antimicrobial, anticancer. Helps rheumatoid arthritis and some forms of depression.

STROPHARIA RUGOSOANNULATA Farl. ex Murrill

King Stropharia, Garden Giant, Burgandy/Wine Cap, Godzilla Mushroom

SPORES: 10–15x6–9 µm, elliptical, smooth, deep purple-brown/black. **STALK:** 7–25x1–7 cm, enlarged at base, white/yellowish/brownish, base often with thick rhizomorphs. **CAP:** 4–20 cm broad, bell-shaped/convex/umbonate/plane, smooth, slightly viscid/dry, deep red/purple/red-brown, fading in age, KOH olive-green on surface. Flesh thick, firm, and white. **VEIL:** Membranous, leaving a thick annulus that is white/blackened by spores and often split into segments. **GILLS:** Adnate/notched/free, crowded, white/gray/purple-gray/purple-black, chrysocystidia present.

RANGE: Mid-Atlantic states, Europe, New Zealand, Japan. **ECOLOGY:** Hardwood forests/mulch/wood chips/straw/lawns/gardens. **GROWTH HABIT:** Scattered/gregarious. **SEASON:** Late spring–early fall.

EDIBILITY: Edible, good taste. 20–24% protein. Great sautéed. Should not be eaten for more than 2–3 days in a row—causes GI distress. Best before veil breaks. **REMEDIATION:** Extracted manganese peroxidase rapid against amino nitro-toluenes. Effective against benzopyrene and PAHs.

CULTIVATION: Tends to clump in LC—must be frequently agitated. LC to grain to sawdust or straw. Does incredibly well on non-treated substrates. Aggressive and highly tolerant of a range of substrates, stressors, and environments. Will not fruit on sterile substrates—needs bacterial interactions. Companions with corn. A great, go-to mushroom—it just keeps on growing!

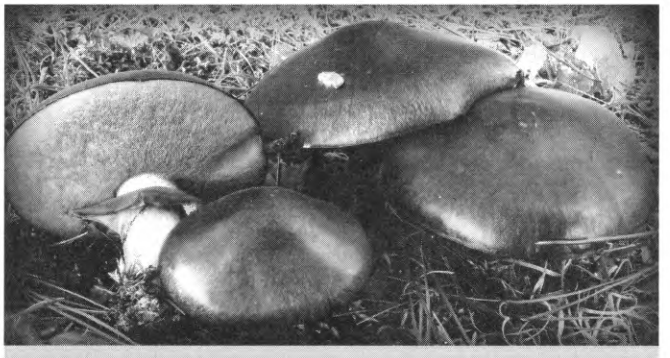
C.40 – Small specimens of *Stropharia rugosoannulata.*

SUILLUS LUTEUS (L.) Roussel
Slippery Jack, Sticky Bun

Spores: 7–9 x 2.5–3 µm, smooth, subfusoid, brown. **Stalk:** 3–8x1–2.5 cm, equal, with glandular dots above ring, whitish/yellowish, discoloring brown/purplish-brown near the base, with flaring white ring that is often gelatinous in humid/wet weather. **Cap:** 5–12 cm, convex/broadly convex/flat, slimy, shiny when dry, margin often with partial veil tissue, dark brown/dark reddish-brown/yellow brown, fading with age, surface gray with KOH or ammonia. Flesh white/pale yellow, not staining on exposure. **Pores:** <1 mm wide, whitish/pale yellow/yellow/olive yellow, not bruising, covered with a whitish partial veil when young. Tubes 4–15 mm deep.

Range: Europe, Asia, North and South America, Southern Africa, Australia, New Zealand. **Ecology:** Mycorrhizal with various conifers. **Growth Habit**: Scattered/gregarious/in large troops/fairy rings. **Season:** Spring–winter.

Edibility: Edible. **Medicinal:** Anticancer, antioxidant.



C.41 – *Suillus luteus.*

TRICHOLOMA MAGNIVELARE (Peck) Redhead
Matsutake, China: *Songxon, Songkuomo,* French: *Tricholome Chaussé,* Japanese: *Matsutake,* Polish: *Rycezyk Matsutake,* Russian: *Ryadovka,* Spanish: *Hongo Matsutake*

Spores: 5–7 x 4–6 µm, white, smooth, elliptical, inamyloid. **Stalk:** 4–15x5 cm, equal/with base slightly tapered, white above the ring, color like cap, very firm—thumb can't crush it. **Cap:** 5–20 cm, convex/broadly convex/flat, dry/a little sticky, margin at first rolled under, white/brownish, odor spicy/funky. **Veil:** Partial veil white, thick, forming a sheath around stem and thick ring. **Gill:** Brown/reddish-brown, stained in age, crowded, attached to stalk. Cystidia and clamp connections absent.

Range: North America, Pacific NW, British Columbia. **Ecology:** Tanoak-madrone stands, pine barrens, and rhododendron/huckleberry/Manzanita habitats, under pines/conifers. Associates with the achlorophlorus plant *Allotropa virgata* (Candy Stick)—a good habitat indicator.

Edibility: Choice—taste spicy, odor distinctive (caused by methyl cinamate). Slice thin, salt, and grill until brown. **Medicinal:** Used for difficult labor, acute gastritis, fevers, convulsions, tonsillitis, antitumor, enhances recovery of NK cells, anti-inflammatory, anti-infectious, antioxidant, helps acute gastritis, inhibits sarcoma 180 and Ehrlich carcinoma, effective against colon cancer, decreases risk of cervical cancer. Useful in facial creams and bath products. **Remediation:** Accumulates arsenic 22x. **Other:** Commercially foraged, primarily shipped to Japan. Collectors sell at US$13–15/lb.

C.42 – *Tricholoma magnivelare,* the North American Matsutake.

VOLVARIELLA BOMBYCINA (Schaeff.) Singer

Silky Volvariella, Tree Volvariella, Silky Sheath, Silky Rosegill, Silver Silk Straw Mushroom

SPORES: 6.5–10x4.5–6.5 µm, elliptical, smooth, pinkish/flesh color. **STALK:** 6–20x1–3 cm, usually tapered up/enlarged below, often curved, smooth, white, firm. **CAP:** 5–20 cm broad, oval/bell-shaped/convex/plane, dry, covered with long silky fibrils, white to yellowish. Flesh thin, soft, white. **VEIL:** Universal veil membranous, often scaly, forming a thick, long, white/yellowish, sac-like volva that sheathes stalk base. **GILLS:** Crowded, free, broad, white/flesh-colored/pinkish.

RANGE: North America, Europe, Asia, Australia, Caribbean, South America. **ECOLOGY:** On dead/live hardwoods (maple/beech/oak/elm/magnolia/mango). **GROWTH HABIT:** Solitary/in small groups. **SEASON:** June–Oct.

EDIBILITY: Edible.

VOLVARIELLA VOLVACEA (Bull.) Singer

Paddy Straw, Chinese: *tsao gu,* Dutch: *Beurszwam,* French: *Volvaire,* German: *Scheidling,* Japenese: *Fukurotake*

SPORES: 7–10x5–7 µm, pink, elliptical, smooth, inamyloid. **STALK:** 4–14x1–2 cm thick, tapering up, with swollen base, dry, whitish/brownish-gray, silky, with a volva that is thick, sac-like, brownish-gray/black up top and whitish below, hairy, hollow. Flesh white. **CAP:** 4–16 cm, ovoid/campanulated conical/flat with dark brown/blackish lines on a whitish/silvery background, velvety, earthy odor, KOH negative on surface. Flesh white. **GILLS:** Free, long, white/pinkish, close/nearly crowded.

RANGE: North America, common east of the Great Plains, tropical and subtropical Asia. **ECOLOGY:** In gardens/sawdust or vegetable residue/compost heaps/wood chips/greenhouses. **SEASON:** Spring–fall.

EDIBILITY: Good when fresh and young. 26–30% protein, 45–50% carbs, 9–12% fiber, 9–13% ash, vitamins B and C, minerals, and assorted amino acids.

CULTIVATION: Fast growing, needs high temps. Rice straw is preferred. Wetted straw is chopped, soaked, stacked in a 2-foot pile, and rested for a day or two. Cottonseed hulls are pre-soaked 2–7 days then layered in the straw at 10–20% along with spawn. Covered for 5–7 days.

C.43 – *Volvariella bombycina.*

Lichens

By Nastassja Noell

Acarospora schleicheri

Gold Cobblestone Lichen **(Plate 36)**

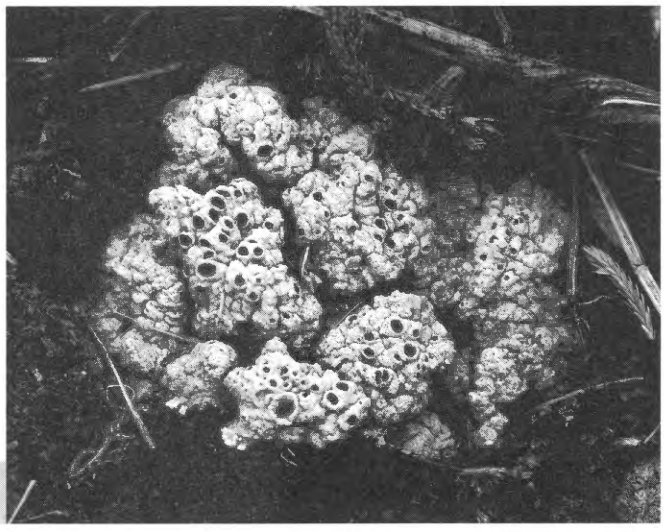
Description: Crustose with a green algal photobiont. The upper surface color and texture is highly diverse throughout the genus, but typical species are areolate with apothecia immersed in the thallus areoles. Asci characteristically contain dozens to hundreds of minute hyaline, single-celled, ellipsoid to globose spores. *Acarospora* chemistry is relatively diverse. Frequently they contain gyrophoric and rhizocarpic acids, but norstictic and various fatty acids are also common. *A. schleicheri* is a relatively large terricolous species with brown apothecia inset like chocolate chips inside a bright yellow thallus.

Ecology: *Acarospora schleicheri* is strictly found on undisturbed soil, usually in more pristine rangelands in the Northern Hemisphere. Most other *Acarospora* species are found on rock and occasionally soil, usually in sunny and arid habitats. They are particularly abundant in deserts and alpine areas.

Human Food and Medicine: The chemical compounds of *Acarospora* species may have medical value, but edibility remains low because of the small thallus size. In arid regions, *A. schleicheri* is a colorful and reliable bioindicator of tertiary succession biotic crust. In regions with asbestos-cement roofs, *A. cervina* creates a bio-protective layer that prevents asbestos from breaking down and spreading into the surrounding environment.

Dye: A variety of red-maroon dyes (AM method) can be made from abundant species such as *Acarospora thamnina.*

Conservation: The Mediterranean endemic *Acarospora placodiiformis* has been recommended for the Fungal Red Listing because it has become increasingly threatened by agriculture, habitat fragmentation, and mining pollution.



L.1 – *Acarospora schleicheri.*

Represented species

Acarospora schleicheri
Bryoria fremontii
Calicium viride
Cetraria islandica
Collema tenax
Dictyonema huaorani
Hypogymnia physodes
Lecanora muralis
Lepraria neglecta s.l.
Lobaria pulmonaria
Melanelia s.l.
Neuropogon lambii
Rhizocarpon geographicum group
Usnea longissima
Xanthoria parietina

Bryoria fremontii

Wila, Edible Horsehair Lichen **(Plate 41)**

Bryoria fremontii, known as Wila by the Interior Salish peoples, is used as a critical winter food staple by humans, caribou, and flying squirrels. The long brown hair of Wila hangs from the trunks and branches of conifer trees and is in reach during long snowy winters. Salish grandmothers were able to tell the difference between the edible *B. fremontii* and its toxic look-alike *B. tortuosa* by taste and feel. Recently, genetic research has demonstrated that these two sympatric lichens actually share the same fungal species. However, it remains a mystery how and why some produce the toxin vulpinic acid and others do not. The lichenologist Trevor Goward suggests these lichens may shift their chemical make-up and morphology through his elegant "Decision-Point Theory." Check out his essays written for the journal *Evansia* on his website waysofenlichenment.org.

Description: Horsehair lichens are fruticose, black to brownish or greenish strands that branch and hang from a central holdfast. *B. fremontii* is typically dark brown to yellowish-brown, occasionally with small soralia containing pale to yellow soredia scattered along the branches along with pale to yellowish streaks called pseudocyphellae. Rarely, tiny yellow apothecia can also be found. All species of *Bryoria* contain quantities of brown melanins (see *Melanelia*), sometimes in addition to various other substances including fumarprotocetraric, protocetraric, and norstictic acids. The cortex and medulla of *B. fremontii* are K-, C-, KC-, UV- (all tests negative). The toxic form of *B. fremontii* (formerly known as *B. tortuosa*) has more contorted branches and contains vulpinic acid, which has a bright yellow color giving the entire lichen a golden cast and yellow soredia and pseudocyphellae.

Ecology: Horsehair Lichens grow mainly on conifers in boreal forests. *Bryoria fremontii* is found in more temperate, dry forests that experience a long cold season followed by a dry warm season. It is most abundant in the interior forests of northwestern North America, Scandinavia, and northern parts of the Eurasian continent.

Human Food and Medicine: *B. fremontii sensu latu* has been used widely by the original peoples from western North America—usually baked into a bread or pemmican with many different roots, herbs, and fruits, or roasted over a fire and then boiled with water to form molasses. *B. fremontii s.l.* does not have secondary chemical compounds that are medicinal.

Dye: *Bryoria fremontii* is said to make a green dye using the AM method, or tan-brown using the BWM method. Other *Bryoria* species create different colors, including yellow by *B. fuscescens* using the BWM method.

Conservation: None. Other species of *Bryoria* and the segregate genus *Sulcaria* are critically imperiled, particularly *B. pseudocapillaris, B. subcana, S. isidiifera,* and *S. spiralifera.* These species are becoming extirpated due to habitat loss, air pollution, and climate change factors in coastal western North America. *S. isidiifera* is an extremely narrow endemic known only from a handful of old growth live oak groves near San Luis Obispo, California.

L.2 – *Bryoria fremontii* in the foothils of Alberta, Canada.

Calicium viride

Green Stubble Lichen **(Plate 43, 44)**

The Calicicales are a fascinating order of lichenized and non-lichenized fungi. These are among our best old-growth indicator lichens and fungi, helping distinguish ancient forests from older secondary growth. And they take a very special eye to see. It's nearly an initiatory experience for budding lichen lovers—until you see them for the first time, you don't see them at all, they are simply invisible. But once someone points them out to you these tiny lichens begin to pop out like magical gnomes in every old growth forest you visit.

Description: Elegant. The algae of lichenized species grows within the substrate or within a patchy crust on the surface, and the fungus emerges, erect, on variously colored stalks about 1 mm tall, topped by a pencil eraser-shaped ascoma called a *mazaedium* in which the asci dissolve, leaving a sooty mass of bare spores. Some Stubble Lichens are yellow, others pink, brown, black, or green. Chemistry is various, but usually not very diverse. *Calicium viride* is one of the largest and most abundant species of Stubble Lichens. It has a conspicuous bright yellow to greenish powdery crust and black pins growing up to a whopping 2.5 mm or more tall. Sometimes the tips are covered with a yellow pruina, especially in a collar underneath the head.

Ecology: Stubble Lichens grow almost exclusively on the undersurface of tree branches, trunks, stumps, logs, and rock overhangs—basically in areas that protect the delicate stalks from direct raindrop impact. A particularly good place to look for them is on so-called "tip-up mounds" created by the upturned root ball of windfallen trees in ancient temperate rainforests. One nonlichenized species, *Chaenothecopsis tsugae*, is known only from the resin of beaver-scarred hemlock in Oregon, USA!

Human Food and Medicine: Too small to be of edible or medicinal value. Many species are used as old growth forest indicators. One example is *Chaenotheca subroscida*, which is only found on trees more than 200 years old in humid temperate to cool temperate forests. It is dispersal limited and thus is severely impacted by forest fragmentation.

Dye: Too small to be of use.

Conservation: Some are highly threatened such as *Chaenotheca xyloxena*, while others such as *Calicium viride* are widespread and locally abundant in many places, even relatively young secondary growth forests.

L.3 – *Calicum viride* in eastern Washington state.

Cetraria islandica

Icelandic Moss **(Plate 45)**

Icelandic Moss, along with Reindeer Moss (*Cladonia spp.*) and a handful of other terricolous (soil-loving) lichens, form the dominant vegetation north of the tree line in arctic regions. They form thick mats as far as the eye can see. Caribou host a special bacterium in their gut that enables them to break down usnic acid, a toxic greenish pigment which is so abundant in these Arctic communities that its spectral signature is detectable from spaceborn satellites. Thanks to this special symbiosis, caribou can survive on lichens (such as Icelandic and Reindeer Moss) as their primary food source in winter months.

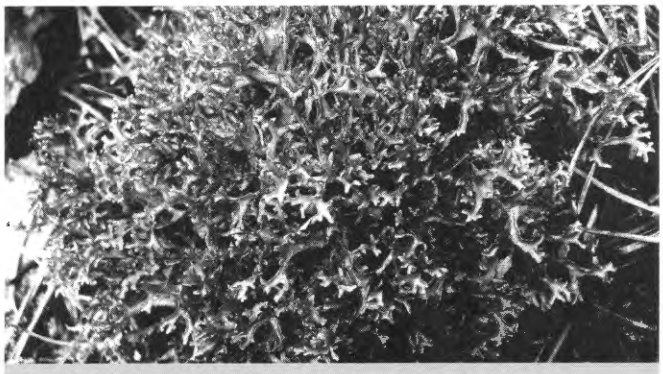
Description: Icelandic Mosses are foliose, green algal lichens. *C. islandica* forms flattened ribbon-like branches that are erect, forming shrub-like mounds a few centimeters tall. The margins have cilia and the lower surface is mottled with irregular white splotches of pseudocyphellae. Apothecia are rarely seen. Chemistry includes fumarprotocetraric, protocetraric, and protolichesterinic acids (K+ dingy brown-yellowish, KC+ pink, P+ orange-red).

Ecology: Most Icelandic Mosses, including *C. islandica*, grow on soil and amongst small shrubs in boreal, alpine, and tundra habitats in both northern and southern hemispheres.

Human Food and Medicine: Nordic peoples have been known to eat *C. islandica*, but because this lichen contains the potent chemical fumarprotocetraric acid, the cousin species *C. ericetorum* may be a more optimal choice since that species contains only fatty acids. As a medicine, fumarprotocetraric acid in *C. islandica* has been found to be potent against different forms of cancer and pathogens. It is important to use this lichen with care as it can accumulate radioactive particles.

Dye: *C. islandica* produces a *y*ellow and brown dye (BWM method). Some of its look-alike species don't contain fumarprotocetraric acid, but may contain other dying chemicals.

Conservation: None yet, but be careful with over harvesting. It usually grows less than 1 centimeter a year, which is fast for a lichen. Additionally, it is a primary foodstuff for caribou.



L.4 – *Cetraria ericetorum* var. reticulata, a relative of *C. islandica*.

Collema tenax

Soil Jelly Lichen **(Plate 40)**

Collema tenax is part of a group of Jelly Lichens that are found throughout the world. Jelly Lichens are nitrogen-fixing lichens that do not segregate the mycobiont and photobiont into separate layers. Rather, the two bionts are intermixed throughout the thallus. Jelly Lichens get their name because they swell dramatically when they are exposed to humid air or water and in these states they have a gelatinous texture and may resemble elderberry jelly. *C. tenax* grows on the soil in arid lands around the world and is an important soil stabilizer and plant community component in deserts and rangelands.

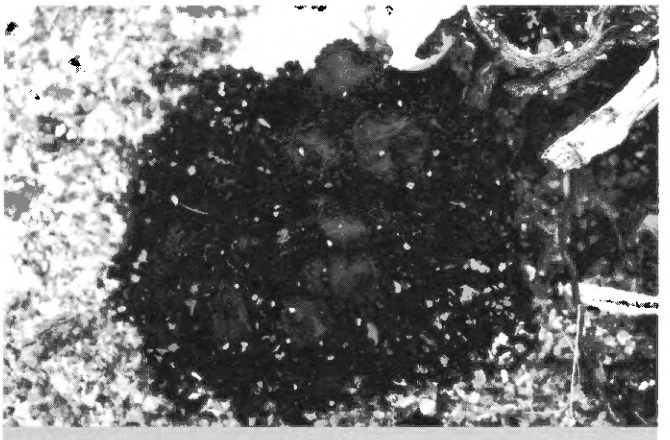
Description: *C. tenax* is a foliose lichen with a cyanobacterial photobiont. It is a small lichen, usually less than 1 cm in diameter, colored blackish to brownish throughout, including the medulla which is usually white in other lichens. It doesn't have a lower or upper cortex, so it tends to be less shiny than members of the closely related genus *Leptogium*. Globose isidia are often scattered over the surface of the lichen, but sometimes there are none. Sometimes you will find little maroon-colored apothecia. Chemistry is minimal as all spot tests are negative.

Ecology: *C. tenax* grows on gypsiferous and calcareous fine soils and thrives in relatively arid habitats, but can also be found in more temperate habitats. It is cosmopolitan, found in Arctic, Antarctic and temperate regions of the northern and southern hemispheres.

Human Food and Medicine: Unknown, and perhaps all *Collema* species are too small to be of much gastronomic or medicinal value. The restoration of rangelands and deserts using *C. tenax* has been undertaken in arid landscapes of western North America, Spain, and China and deserves more attention.

Dye: No secondary chemicals are known from *Collema* species.

Conservation: None.



L.5 – *Collema tenax.*

Dictyonema huaorani

Nénéndapé

Hallucinogenic lichens? Yup, and this is one of them. The Waorani (Huaorani) people of Amazonian Ecuador consume a hallucinogenic tea made from Nénéndapé during shamanic practices. But finding it isn't easy. It is so rare that the species was recently described from only one specimen that was stored in a paper envelope for over 30 years.[1]

Description: *Dictyonema* species are foliose lichens with a cyanobacterial photobiont. Most, like *D. huaorani*, form clusters of thin shelf mushrooms about 19x9 cm in size, about 0.5 mm thick. It looks similar to the Turkey Tail mushroom, however it has an aquamarine to green color on the upper surface with a white lower surface. Spot tests are K-, C-, KC-, P-.

Ecology: *D. huaorani* is a basidiolichen that grows on rotting wood in the northwestern Amazon forest in areas with ample light. Other species of *Dictyonema* can be found throughout the world's tropics, especially in montane regions.

Human Food and Medicine: *D. huaoranii* is used by peoples in Eastern Ecuador as a hallucinogen. Chemicals from the 30-year-old specimen noted above were compared to "non-authentic standards" (there's a story!) of 5-MeO DMT, psilocybin, and three types of tryptamine and got a positive hit for all those chemicals.[2]

Dye: Probably no dye chemicals, all spot tests negative.

Conservation: Knowledge of its range is limited to only one specimen, so maybe it's extirpated or locally abundant or maybe even widespread and just rare. We don't know. If you do find some, please be respectful of the Waorani and their deep relationship with this lichen.

L.6 – *Cora glabrata* was formerly in the *Dictyonema* genus.

Hypogymnia physodes

Hooded Tube Lichen **(Plate 38)**

Description: Tube Lichens are a diverse group of foliose chlorolichens that all have hollow branches. The exterior of these tubes typically has an underside that is black and a gray to white upper side. The interior is either white or black and this is a taxonomic feature, as are the details of the branching pattern and presence of different types of reproductive structures. *Hypogymnia physodes* is characterized by a white interior and distinctive hood-shaped soralia bursting from the inside of openings in the branch tips. The upper cortex of most species contains atranorin (K+yellow), however some species in Asia contain usnic acid (K-, KC+ yellow). The medulla contains various chemicals ranging from orcinols to beta-orcinals. *H. physodes* contains a complex cocktail of physodic, physodalic, protocetraric acids (KC+ rose, P+ orange-red), and traces of several others.

Ecology: Tube Lichens are found growing on wood and sometimes rock throughout the world, primarily in more temperate to boreal habitats that have more than 25 centimeters of precipitation a year, but some thrive in coastal desert ecosystems such as *Hypogymnia schizidiata*. *H. physodes* is found throughout the northern hemisphere.

Human Food and Medicine: Most Tube Lichens contain atranorin and other medicinally potent chemicals that make it better suited for medicine than as a food. However, their greatest application is found in their bioindicator potential. *H. physodes* is a favored bioindicator of air quality because it can tolerate high levels of pollutants and accumulate them into its thallus, giving humans an understanding of the invisible toxins in the air. These can include mercury and methylmercury in metal extraction regions, sulfur dioxide in fossil fuel and fertilizer production, ozone pollution in urban and industrial areas, as well as lead and cadmium pollution.

Dye: Highly valued for a variety of colors, particularly *Hypogymnia physodes* for gold, orange, green (using mordant), tan, and warm brown (BWM). Try playing with pH levels in your rinse wash to diversify colors.

Conservation: None.

L.7 – *Hypogymnia physodes* in eastern Montana.

Lecanora muralis

Stonewall Rim Lichen **(Plate 39)**

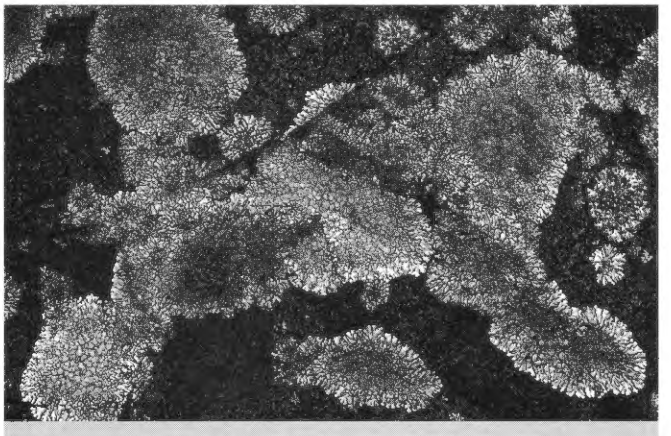
Description: *Lecanora* is one of the most diverse lichen genera in the world with well over 500 described species. Almost all are crustose lichens with a green algal photobiont and disc-shaped apothecia in which, importantly, the apothecial margin contains algae and is the same color as the crustose thallus. The asci of Rim Lichens have a complex apparatus at the tip that helps eject the spores (resulting in a distinctive *Lecanora*-type ascus stain. And most species have crystals in the apothecia that light up in polarized light under the microscope. They are potentially one of the most chemically diverse genera of lichens. *L. muralis* is a distinctive, beautiful species with a conspicuous, blueish to greenish-gray, lobed, rosette-shaped thallus. It is but one of a large group of similar species sometimes collectively called the *Lecanora muralis* group. *L. muralis* in the strict sense is perhaps the most widespread species in the group, it is distinguished by relatively flattened to almost concave lobes, and a characteristic discontinuous algal layer in which compact transparent bundles of hyphae poke holes in the algae to allow more sunlight to reach the inner parts of the thallus.

Ecology: Rim Lichens are generally found growing on wood and rock, but also sometimes on soil. They are found all around the world, from pole to pole, tropics to Arctic, desert to forest. *Lecanora muralis* is just as successful as the genus, occurring on all continents in a wide range of habitats and types of rock and occasionally even on weathered wood such as dusty fenceposts.

Human Food and Medicine: Too small to be of much value as food or medicine, these species have high potential as bioindicators of air pollution. *L. conizaeoides* requires sulfur dioxide, thus declines in this species correlate with improvements in air quality. Conversely, *L. muralis* has been used to measure urban pollution levels of zinc, cadmium, lead and other heavy metals. *L. muralis* has also been used to measure rates of climate change and glacier retreat in mountains including the Tien Shan Mountains in Central Asia.

Dye: Various colors, including reds by *L. taratarea* (AM method), and olive by *Lecanora muralis* (BWM method).

Conservation: None.



L.8 – *Lecanora muralis* in eastern Washington state.

Lepraria neglecta s.l.

Powder Lichen **(Plate 47)**

Description: Leprose (i.e. amorphous masses of small dust-like balls of fungal hyphae entangling green algae). *Lepraria spp.* are usually whitish, grayish, blueish, or greenish in color. The individual soredia-like balls of thallus average around 0.05 mm in diameter, but the clustered thalli can grow to many centimeters across. Chemistry is highly diverse and is important for the differentiation of species. *Lepraria neglecta* (in the broad sense of Lendemer 2013[3]) is one of the few species of Powder Lichens that is readily identifiable in the field with practice. It forms a unique "pseudocortex," giving the individual thallus balls a compact corticate-like appearance (bring your hand lens!). This pseudocortex allows *L. neglecta* to grow in exposed locations that are typically too climactically variable for other leprose species.

Ecology: Powder Lichens grow on rock, trees, and soil around the world, primarily in somewhat moist, shaded microhabitats. *Lepraria neglecta* is common and widespread in bright sunny situations throughout the northern hemisphere from temperate mountains to the Arctic. It is most abundant on soil, mosses, and other organic matter, but is also found on noncalcareous rocks.

Human Food and Medicine: Not known.

Dye: Not known.

Conservation: Some species have been suggested for conservation, including *Lepraria lanata,* which is narrowly endemic to high elevation habitats in the southern Appalachian mountains.

L.9 – *Lepraria neglecta s.l.* in southern Arizona.

Lobaria pulmonaria

Lungwort **(Plate 34)**

Lobaria species love to hang out in the humid canopy of temperate rainforests, making them among the best indicators of old growth forests and sylvan health. Sadly, in many parts of Europe where few natural old growth forests remain, Lungworts are nearly extirpated. Additionally, Lungwort is very sensitive to air pollution and shrivels and dies downwind of urban and agricultural areas. But in pristine forestlands Lungwort is an ecosystem driver, contributing up to 50% of the fixed nitrogen to ancient forest ecosystems. The bright green color of Lungwort makes this lichen easily mistaken for a chlorolichen, but in fact it is a tripartite symbiosis: both cyanobacteria and green algae thrive in its thalli. If you look very closely under a microscope you will see the nitrogen-fixing cyanobacteria curled up in dark blue-gray nodules (cephalodia) that are initially resting on the upper surface and later carried within the medulla and beneath the lower surface by fungal hyphae.

Description: Lungwort is a foliose lichen with a green algal photobiont layer and dark blue cyanobacteria contained in cephalodia that are scattered within and about the thallus. It is

one of the larger epiphytic lichens, regularly growing to sizes larger than your hand. When wet the upper surface is bright green, and when dry it is tanish-brown. The lower surface lacks a cortex and is a soft, pale tan to pinkish-cream color. The upper surface has a conspicuous network of ridges throughout, and soredia or isidia form on the edges (marginal) and ridges (laminal). Apothecia are usually rare. Chemistry includes stictic, norstictic, and constictic acids (K+ yellow to brown or red, KC-, C-, P+ orange).

Ecology: *L. pulmonaria* grows on mature deciduous and coniferous trees in older growth temperate forests, usually in the canopy of coniferous or deciduous trees where humidity and dry air fluctuate and there is a good amount of light. It is found throughout the northern hemisphere, including parts of Europe, Asia, North America, and Africa.

Human Food and Medicine: *L. pulmonaria* has been used in medicinal treatments by peoples around the world for various ailments of the lungs and respiratory tract due to its similar appearance to lung tissue. Recent biomedical research has shown *L. pulmonaria* to have strong anti-ulcer affects as well as moderate anti-inflammatory qualities.[4]

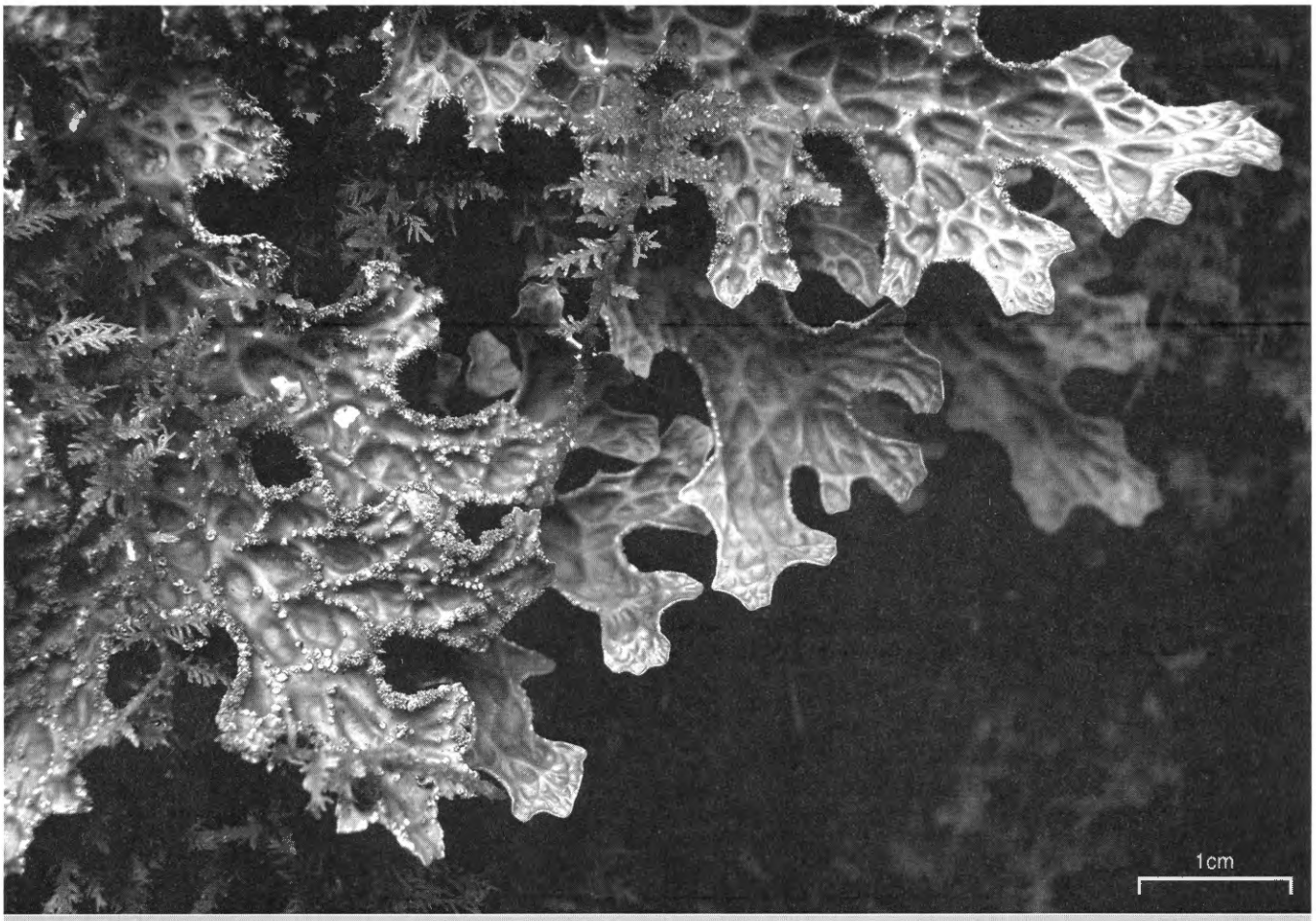
Dye: Stictic, norstictic, and constictic acids produce an orange color using the AM method.

Conservation: *L. pulmonaria* is declining in Europe and is red-listed as a rare species by the IUCN. Its status in Canada ranges from stable to critically imperiled. The United States government has not ranked this species.

Melanelia s.l.

Camouflage Lichens

Description: Brown, brown, and brown. *Melanelia spp.* are large foliose lichens with a green algal photobiont that often turn olive green when wet. Some have isidia, others soredia or apothecia. The chemistry can be somewhat variable, but all have melanins in the outer cortex. The white cottony interior often contains various chemicals including especially lecanoric and occasionally fumarprotocetraric and stictic acids. Many, such as those in the segregate genus *Melanohalea*, contain no acids.



L.10 – *Lobaria pulmonaria.*

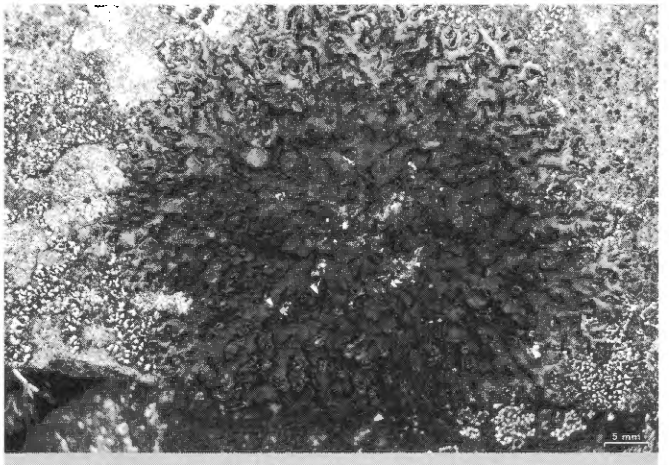
The brown pigments, generically known simply as melanins, are poorly understood chemically. They are apparently unrelated to the vast majority of secondary metabolites produced by lichens, such as the orcinol depsides and depsidones. However, studies have shown that the dark coloration absorbs sunlight and can raise the thallus temperature as high as 176°F (80°C) in the dead of winter! Since most proteins involved in photosynthesis cannot function in freezing temperatures, this heat sinking ability allows Camouflage Lichens (and other related dark brown genera, such as *Umbilicaria*) to grow during long, deadly winters on windswept outcrops in the alpine and Antarctic where no other plants can survive.

Ecology: Camouflage Lichens grow on wood and rock throughout the world, but primarily in temperate to boreal regions in microhabitats with lots of sunlight and moderate amounts of moisture.

Human Food and Medicine: Though not commonly eaten, some species may contain medicinal secondary metabolites.

Dye: Orange to brown for *Melanelia stygia, M. acetabulum, Melanohalea olivacea,* and *Cetrariella commixta* (BWM method). *Melanelixia glabratula* produces a fuschia color (AM method).

Conservation: None.



L.11 – *Melanelia hepatizon* in the foothills of Alberta, Canada.

Neuropogon lambii

Zebra Beard Lichen **(Plate 35)**

Neuropogon lambii, and other species in the *Neuropogon* group, is one of the most striking alpine lichens. Their green and black striped branches soften boulders into furry surfaces, particularly in the southern hemisphere where over a dozen species thrive and have diversified across the southern Andes, Antarctica, New Zealand, and Australia. In contrast, the northern hemisphere has developed only a few species. Gondwana, the subcontinent of Pangaea, may have been more favorable to *Neuropogon* than Laurasia, but our knowledge of the paleoclimates of these regions is limited. Either way, the black stripes on the Zebra Beard helps the lichen heat up during cold sunny days, while the green sections photosynthesize and contain usnic acid with all its healthful properties. The joy and mystery of finding this lichen while climbing through snowy mountain passes is delightful.

Description: *Neuropogon* is now often included as a subgenus of *Usnea* (see below). As a group, *Neuropogon* species are fruticose, green algal lichens that attach to rocks at a central location, with solid erect branches that ascend upward like a tiny tree. The branches have usnic green and melanic black stripes. Many have black or pinkish colored apothecia at the end of the branches, while others have soredia. The Flora of New Zealand has a great key to the lichens of that region. Chemically, the outer cortex contains usnic acid and melanins. The medulla chemistry is variable within the genus.

Ecology: *N. lambii* is found growing on rocks in alpine areas in the northern and southern hemisphere, but other species of *Neuropogon* are much more abundant, diverse, and widespread in the alpine of the southern hemisphere.

Human Food and Medicine: Not known for edibility, but the usnic acid and melanins found in *Neuropogon* species have medicinal properties including anti-cancer and immune stimulation.

Dye: Variable, depending on species. Usnic acid will produce a yellow to brown dye using the BWM method. Some species have other chemicals including fumarprotocetraric and salazinic (red-maroon dye using AM method) as well as protocetraric and norstictic acid (yellow-orange dye, BWM method).

Conservation: *N. lambii* is extremely rare in most parts of the northern hemisphere and needs conservation attention. In the southern hemisphere, populations of other *Neuropogon* species are more stable and viable.

L.12 – *Neuropogon spp.* in Isla Navarino, Chile.

Rhizocarpon geographicum group

Golden Map Lichen **(Plate 46)**

Rhizocarpon geographicum is one species of a taxonomically complex group of lichens, collectively known as the *R. geographicum* group. Found throughout the world, these similar looking lichen species are often used in lichen dating techniques (lichenometery) to date the retreat of glaciers, petroglyphs, ancient ruins, and even Indigenous people's cairns. The species in this group are indistinguishable without a microscope and chemical spot tests, but that shouldn't take away from their beauty and the awe that this group of lichens can instill. It is one of the primary lichens being used to understand astrobiology. Did life originate somewhere other than Earth? Perhaps, and lichens might be a source. *R. geographicum* has been tested to withstand the conditions of outer space (vacuum pressure, extreme sub-zero temperatures, and intense hard radiation) as well as hypervelocity impact simulations and simulations of life on Mars. What would be a better seed of life than a self-contained microecosystem of fungus, plant, and bacteria?

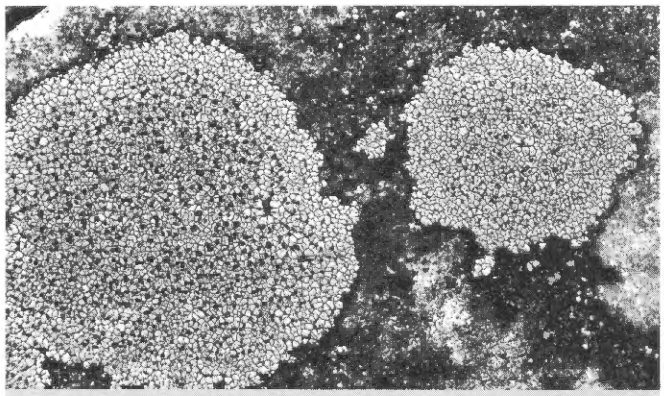
Description: The Map Lichens are areolate crustose, green algal lichens. Areoles and apothecia are generally mixed amongst each other, often sitting on a thin layer of black fungal tissue especially visible radiating like a halo around the margins of the thallus (hypothallus). The color of the upper cortex usually ranges from yellow to green for the *R. geographicum* group to purplish, grayish, and brownish in other species. The apothecia are always black with a black margin that frequently disappears with age, and are often inset between thallus areoles. The distinctive spores can be colorless or gray to dark brown, 1-septate to muriform, but always with a gelatinous sheath creating a faint halo (easiest to see in India ink mounts). Chemistry is highly diverse in the genus. Species may contain a variety of depsides, depsidones, and/or pulvinic acids.

Ecology: Species in this group grow almost exclusively on non-calcareous rock, at different elevations but especially in montane areas. The different chemistry and spore types of species in this group may correspond with substrate and microclimatic variables. A number of species in the *R. geographicum* group are parasitic on other crustose lichens (e.g. *R. pusillum* on the ubiquitous alpine crustose lichen *Sporastatia testudinea*). These species are initially parasitic, meticulously replacing the hyphae of the host lichen with their own hyphae, respectfully ensuring continuity and stability for the photobiont. Once the host is completely taken over, the juvenile parasite becomes a full-fledged free-living lichen.

Human Food and Medicine: Bleaching of the thallus of *Rhizocarpon geographicum* species has been used as an indicator of acid rain. Their medicinal value is unknown, but this group has complex chemistry and contains medicinally powerful compounds including psoromic acid, stictic acid, barbatic acid, and gyrophoric acid.

Dye: The colors produced by *Rhizocarpon geographicum* can vary from thallus to thallus. Even within *R. geographicum sensu stricto*, the chemistry is highly variable, even from thalli on the same rock! If you love surprises, this is the lichen dye-stuff for you!

Conservation: None.



L.13 – *Rhizocarpon riparium*, a close relative of *R. geographicum*.

Usnea longissima

Old Man's Beard Lichen **(Plate 34)**

Usnea longissima is one of the most striking and conspicuous *Usnea* species, but it is also one of the most threatened from deforestation and over-collection because of the medicinal properties of usnic acid. Other species in the *Usnea* genus also contain usnic acid, as do many other genera, most of which are far more abundant than *U. longissimma*. Propagation of this lichen has been quite creative, including slingshotting fragments inside water-filled (biodegradable!) condoms to establish "seed" populations in the upper canopy of temperate rainforests of the Pacific Northwest.

Description: The Beard Lichens (*Usnea spp.*) are rather stereotypical in form, easily confused with look-alike chlorolichens, including *Alectoria spp.*, *Bryoria spp.* (see species description), and *Ramalina thrausta*. *Usnea* species contain a characteristic and unique rubbery central cord that can be best observed by pulling a moistened branch into two. Additionally, they are usually a pale milky "usnic" green unlike the brown *Bryoria* species, and have abundant short perpendicular fibrils that are not found in *Alectoria* and *Ramalina* species. The various species of *Usnea* have different morphologies that vary from erect tufts to beard-like droops. The most elegant is *Usnea longissima,* which forms singular long strands that can grow to be dozens of meters long and festoon trees in old growth forests like holiday bunting. *U. longissima* only reproduces by fragmentation, while other *Usnea* species have soredia, isidia, or apothecia. Chemical spot tests for *U. longissima* (cortex): K-, KC+ pale yellow, C-, PD-; (medulla): K-, C-, KC- PD-; other *Usnea* species may be different for medulla spot tests.

Ecology: Beard Lichens are common in the canopy of temperate and boreal forests around the world, and are especially abundant and diverse near the coast. *Usnea longissima* grows in old-growth temperate rainforests in North America, Scandinavia, Europe, Asia, and Africa. It is sensitive to air pollution and habitat fragmentation and requires forest continuity and clean air to thrive.

Human Food and Medicine: Beard Lichens are not used as food, but they are widely used for medicinal purposes by cultures around the world. Biomedical research has demonstrated that usnic acid inhibits cell growth and proliferation of breast cancer and pancreatic cancer, and is potent against a variety of pathogens. Heat treatment (e.g. slow cooked infusion) of Beard Lichens prior to making a tincture can make the usnic acid component more bioactive and potent if that is desired. Be sure you do chemical spot tests to know which chemicals are in the species you are using so that contraindications can be considered.

Dye: *U. longissima* makes a yellow to brown dye in BWM. Other *Usnea* species can produce red to maroon using the AM method.

Conservation: *U. longissima* is threatened throughout its range. Small areas may be locally abundant in this species, however all of these habitats should be considered critical, and therefore protected to prevent extirpation of *U. longissima* from the broader region. Similarly, *U. angulata*, once widespread, has been dramatically reduced in eastern North America, and is now essentially restricted to a handful of "anthropocene refugia" such as the Great Smoky Mountains. Fortunately, most other species of *Usnea* are not in such dismal situations.

L.14 – *Usnea longissima.*

Xanthoria parietina

Sunburst Lichen **(Plate 42)**

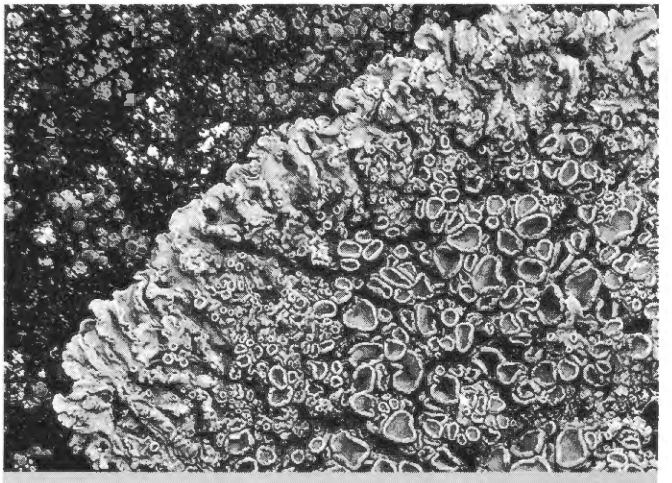
Description: Sunburst Lichens, including the recent segregate genus *Xanthomendoza*, all share a more or less foliose structure, green algal photobiont, and a bright orange color that is K+ purple. Some have apothecia, others have soredia and the location of these is an important taxonomic character. *X. parietina* is easily distinguishable from related species by its large, broadly-adnate, spreading marginal lobes forming sunburst-like yellow to orange rosettes on trees and rocks, along with its central cluster of orange disk-like apothecia.

Ecology: Sunburst Lichens are usually found growing on wood, bark, and sometimes rock in urban, suburban, and agricultural areas, and near bird roosts, rodent dens, and other nitrogen-enriched microhabitats. You can often see their colonies from a distance as what appears to be orange or yellow spray paint. *X. parietina* is one of only a few well-documented weedy lichens. It frequently hitchhikes on ornamental trees into new areas. It can now be found in urban areas throughout the interior of Washington State, USA and British Columbia, Canada while just a few decades ago it was only known from the coast.

Human Food and Medicine: *X. parietina* has been found to be highly effective against cancer, microbes, and fungal pathogens. Its orange pigment, the anthraquinone parietin, is also being investigated for use in sunscreen and UV filters. As a food they're too small to be of much value, and since they accumulate pollutants it's not recommended to eat them. *Xanthoria spp.* are widely used as bioindicators of air quality and pollution.

Dye: Sunburst Lichens are a good dye lichen as they are abundant in disturbed areas. They create a photoxidative dye that changes from pink to blue in sunlight (AM method followed by POD method).

Conservation: None.



L.15 – *Xanthoria parietina* in Acadia National Park, Maine.

APPENDICES

Appendix A

ID Forms

The following forms are designed to aid in identification of the most commonly encountered types of macro fungi. The front side of the forms (those with a title) detail the characteristics of an average specimen from a collection. There is a generic back sheet that can be used for all of the types. This back sheet includes descriptors for ecological traits, growth habits, and microscopic features. Not all of these will apply to a given collection. Following the forms are field tags used for tracking collections. The lichen identification form was designed by Nastassja Noell. A few things to note:

- All measurements should be recorded in millimeters (mm).
- To preserve spore prints, use an acid-free spray fixative or transparent tape.
- Many descriptors can be used for mushroom scents. These include almond, anise, beany, bleachy, carrion, cedar, citrus, earthy, farinaceous, fishy, fragrant, fresh, fruity, musty, not distinct, phenolic, potato-like, pungent, radish-like, sharp, spermatic, spicy, strong, sweet, unpleasant, and weak.

Survey and Manage Description Form – Gilled Fungi

Taxon: _____
Date: _____
Collector(s): _____
_____
Collection number: _____
Photo Number(s): _____

General Characteristics

Entire height: _____ Cap width: _____
Cap center height: _____ Odor: _____
Taste (*don't swallow*): Mild - Strong - Pleasant - Unpleasant
Peppery - Other: _____

Color (gradations, spots, streaks, bruising reactions, changes)

Spore print: _____ Hygrophanous: N - Y Cap surface: _____ Cap flesh: _____
Immature gills: _____ Mature gills: _____ Gill edge: Concolorous - Darker - Lighter
Stem surface: _____ Stem flesh: _____

Cap Characteristics

Latex: N - Y Latex color: _____ Surface texture: Dry - Greasy - Sticky - Slimy - Other: _____
Surface ornamentation: Smooth - Pubescent - Fibrillose - Cracked - Wrinkled - Scaly - Granular - Warty - Other: _____
Shape: Bell-shaped - Convex - Conic - Cylindrical - Depressed - Funnel - Mammilate - Plane - Umbilicate - Umbonate - Upturned - Other: _____ Margin shape: Straight - Uplifted - Recurved - Inrolled - Incurved - Other: _____
Contours of margin: Striate - Even - Wavy - Irregular - Appendiculate - Other: _____
Flesh consistency: Fleshy - Brittle - Spongy - Tough - Chalky - Other: _____

Gills

Gill attachment to stem: Free - Adnexed - Adnate - Sinuate - Decurrent - Other: _____
Gill edge shape: Entire - Scalloped - Wavy - Serrate - Eroded - Other: _____ Gill texture: Waxy - Brittle - Soft
Gill pattern: Alternate - Anastamosing - Dichotomously branched - Irregularly branched
Gill thickness: Narrow - Moderate - Broad Gill spacing: Distant - Subdistant - Close - Crowded

Veil

Partial veil: None - Membranous - Fibrillose - Cortina - Slimy Veil color: _____

Annulus

Type: None - Single - Double Position: Apical - Central - Basal Shape: Skirtlike - Intermediate - Sheathlike

Universal veil

Universal veil present: N - Y Volva: None - Saccate - Collared - Sheathing - Zoned Volva color: _____
Universal veil remnant(s) on cap: Patch - Warts - Other Color of remnant(s): _____

Stalk Characteristics (if present, use cross-section for measurement)

Stalk present: N - Y Length: _____ Width at widest point: _____ Width at base: _____
Flesh texture: Gelatinous - Firm - Solid - Stuffed - Hollow - Flimsy/fragile - Other: _____
Shape: Equal - Ventricose - Tapered at apex - Tapered at base - Radicate - Clavate - Bulbous - Twisted - Other: _____
Surface texture: Viscid - Sticky - Dry - Polished - Smooth - Fibrillose - Punctate - Other: _____
Surface ornamentation: Smooth - Powdery - Scaly - Fibrillose - Tomentose - Other: _____
Stem consistency: Cartilaginous - Fibrous - Chalky - Other: _____

Chemical Characteristics

KOH - cap surface: _____ Melzer's - cap surface: _____ KOH - flesh: _____
Melzer's - flesh: _____ KOH - partial veil: _____

Survey and Manage Description Form – Boletoid and Polyporous Fungi

General Characteristics

Sporocarp type: Bolete - Polypore Cap width: _____
Entire height: _____ Odor: _____
Taste (*don't swallow*): Mild - Strong - Pleasant - Unpleasant
Peppery - Other: _____

Taxon: _____
Date: _____
Collector(s): _____
_____
Collection number: _____
Photo Number(s): _____

Color *(gradations, spots, streaks, bruising reactions, changes)*

Cap surface: _____ Cap flesh: _____ Pore layer: _____ Stem surface: _____
Stem flesh: _____ Bruising reactions: _____

Cap Characteristics

Cap shape: Convex - Plane - Uplifted - Irregular - Centrally depressed - Other: _____
Surface texture: Dry - Greasy - Sticky - Slimy Flesh consistency: Fleshy - Brittle - Spongy - Other: _____
Surface ornamentation: Smooth - Pubescent - Fibrillose - Cracked - Wrinkled - Scaly - Granular - Velvety - Other

Stalk Characteristics *(if present, use cross-section for measurement)*

Length: _____ Width at widest point: _____ Width at base: _____
Stalk shape: Equal - Ventricose - Tapered at apex - Tapered at base - Clavate - Bulbous - Other: _____
Surface texture: Viscid - Sticky - Dry - Polished - Glabrous - Fibrillose - Punctate - Other: _____
Flesh texture: Gelatinous - Firm - Solid - Stuffed - Hollow - Other: _____
Ornamentation: None - Glandular - Dotted - Powdery - Scabrous - Scaly - Fibrillose - Finely reticulate - Coarsely reticulate
Location of reticulum: None - Apex only - Top of stem - Entire stem - Other Color of ornamentation: _____
Annulus: None - Membranous - Fibrillose - Cortina - Slimy Annulus color: _____

Survey and Manage Description Form – Club, Veined, Toothed, and Jelly Fungi

General Characteristics

Sporocarp type: Club-like - Veined - Toothed - Jelly
Entire height: _____ Odor: _____
Taste (*don't swallow*): Mild - Strong - Sweet - Bitter - Peppery -
Other: _____
Flesh consistency (*in cross-section*): Gelatinous - Fleshy -
Brittle - Tough - Rubbery - Spongy

Taxon: _____
Date: _____
Collector(s): _____
_____
Collection number: _____
Photo Number(s): _____

Colors

Cap color: _____ Cap flesh: _____ Flesh bruising: _____ Hymenium color: _____
Stem surface: _____ Stem flesh: _____ Stem bruising: _____

Cap Characteristics

Width: _____ Flesh thickness: _____
Texture: Smooth - Pubsecent - Scaly - Granular - Warty - Fibrillose - Greasy - Sticky - Dry - Silky - Hygrophanous

Stem Characteristics *(if present, use cross-section for measurement)*

Stem Present: N - Y Length: _____ Width at widest point: _____ Width at base: _____
Stem shape: Equal - Ventricose - Tapered at apex - Tapered at base - Compressed - Other: _____
Surface: Dry - Moist - Viscid - Smooth - Tomentose - Ribbed - Scaly - Folded - Grooved - Wrinkled - Fibrillose - Other
Flesh texture: Gelatinous - Firm - Solid - Stuffed - Hollow

Survey and Manage Description Form – Elfin and Cup Fungi

Taxon: _____
Date: _____
Collector(s): _____
_____
Collection number: _____
Photo Number(s): _____

General Characteristics

Sporocarp type: Morel types - Elfin saddles - Cup
Shape: Cup - Disk - Cushion - Rabbit-ear - Truncate - Club - Spatulate - Saddle-stipitate - Brain-stipitate - Pitted-stipitate
Taste (*don't swallow*): Mild - Strong - Sweet - Bitter - Peppery - Other: _____ Odor: _____
Entire height: _____ Length of stem: _____
Width of cap: _____ Cap flesh thickness: _____ Flesh color and bruising: _____
Hymenium color (*spore-bearing surface*): _____ Abhymenium color (*opposite spore-bearing surface*): _____
Abhymenium texture: Smooth - Pubescent - Scaly - Granular - Warty - Fibrillose - Greasy - Sticky - Dry - Silky - Hygrophanous
Flesh consistency (*in cross-section*): Gelatinous - Fleshy - Brittle - Tough - Rubbery - Spongy - Other: _____

Chemical Characteristics

Asci stain in iodine: None - Amyloid - Dextrinoid Nuclei stain red in acetocarmine: N - Y
Spore ornamentation staining: in cotton or aniline blue: N - Y In lactic acid or lactophenol: N - Y

Stalk Characteristics *(if present, use cross-section for measurement)*

Stalk present: N - Y Length: _____ Width at widest point: _____ Width at base: _____
Shape: Equal - Ventricose - Tapered at apex - Tapered at base - Compressed - Other: _____
Stem flesh texture: Gelatinous - Firm - Solid - Stuffed - Hollow - Other: _____
Flesh color: _____ Surface color: _____
Surface: Dry - Moist - Viscid - Smooth - Tomentose - Ribbed - Scaly - Folded - Grooved - Wrinkled - Fibrillose - Other

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Survey and Manage Description Form – Sequestrate Fungi

Taxon: _____
Date: _____
Collector(s): _____
_____
Collection number: _____
Photo Number(s): _____

General Characteristics

Height: _____ Width: _____
Shape: Globose - Subglobose - Irregular - Top-shaped
Overall consistency: Tough - Crisp - Rubbery - Friable - Hard - Powdery inside Odor: _____

Peridium *(outer surface)*

Thickness: _____ Layers: One - Two - Three
Texture: Warty - Smooth - Tomentose - Wrinkled - Folded - Crusty Separable from gleba: N - Y
Color at collection: _____ Color changes or bruising: _____ 5% KOH response: _____
Rhizomorphs: None - Attached at base - Attached along sides - Attached overall Rhizomorph color: _____

Gleba *(inner portion, describe when cut in half)*

Color: _____ Arrangement: Solid - Veined - Gilled - Convoluted - Chambered
Texture: Powdery - Cottony - Marbled - Gelatinous - Waxy Latex present: N - Y Latex color: _____
Columella: None - Single - Robust - Joins apex at peridium - Dendroid Stem: None - Basal pad - Distinct stem

Survey and Manage Description Form – Coral Fungi

Taxon: _____
Date: _____
Collector(s): _____
_____
Collection number: _____
Photo Number(s): _____

General Characteristics

Entire height: _____ Crown diameter: _____
Stem width: _____ Stem base width: _____
Taste (*don't swallow*): Mild - Strong - Pleasant - Unpleasant - Bitter - Acrid - Other: _____ Odor: _____

Surface Color (*color gradations, spots, streaks, and bruising*)

Tips: _____ Branches: _____ Stem: _____ Bruising (*color and location*): _____
Yellow band at stem and branch junctions (*fades after picking and in older specimens*): N - Y

Flesh Color in Cross-Section

Tips: _____ Branches: _____ Stem: _____
Rusty root present (*brown band in lower cross-sectioned stem*): N - Y

Branch and Stalk Characteristics

Stalk form: Massive - Chunky - Slender - Single - Fused - Fascicled Rhizomorphs present: N - Y
Flesh consistency (*one or more*): Solid - Hollow - Fleshy-fibrous - Brittle - Rubbery-cartilaginous - Firm-cartilaginous Slimy-cartilaginous - Marbled-gelatinous - Other: _____
Branch consistency: Fragile - Firm - Fleshy-fibrous - Cartilaginous - Brittle - Rubbery - Firm-gelatinous - Slimy-gelatinous
Melzer's reagent on stem interior: None - Amyloid - Dextrinoid
Green reaction to ferrous sulfate: None - Flesh interior - Hymenium

Growth Habit

Spore Print

PREVALENCE: Scarce - Occasional - Common - Abundant
SPECIMEN AGE: Immature - Mature - Old - Mixed
HABIT: Single - Scattered - Caespitose - Grouped - Esupinate - Effuso - Reflexed - Shelving - Upright
DUFF SUBSTRATE: Conifer cone - Leaves - Needles - Twig litter
SOIL SUBSTRATE: Mineral - Humus WOODY SUBSTRATE: Conifer - Deciduous
WOOD SPECIES: _____ HOW DECAYED: _____ OTHER SUBSTRATE: _____

Ecology

LOCATION/GPS: _____ LOCALITY: _____ ELEVATION, ASPECT: _____
CLIMATE: _____ RECENT WEATHER: _____ AIR TEMP./HUMIDITY: _____

Specimen Sketch

HABITAT: Conifer forest - Deciduous forest - Mixed forest - Bog - Riparian Meadow - Pasture - Lawn - Landscaping - Desert - Bare soil - Burn - Other
SOIL TYPE(S): _____ SOIL TEMP./MOISTURE: _____
HABITAT AGE: _____ PREVALENT PLANTS: _____

Microsopic Characteristics

SPORE COLOR: _____ SPORE ORNAMENTATION: _____
SPORES AMYLOID: N - Y SPORE SIZE & SHAPE: _____
CYSTIDIA: N - Y CYSTIDIA TYPES(S) & SIZE : _____
ASCI: Operculate - Inoperculate CLAMP CONNECTIONS: N - Y
HYPHAL TYPES: Generative - Binding - Skeletal
GILL TRAMA: Divergent - Parallel - Convergent

Growth Habit

Spore Print

PREVALENCE: Scarce - Occasional - Common - Abundant
SPECIMEN AGE: Immature - Mature - Old - Mixed
HABIT: Single - Scattered - Caespitose - Grouped - Esupinate - Effuso - Reflexed - Shelving - Upright
DUFF SUBSTRATE: Conifer cone - Leaves - Needles - Twig litter
SOIL SUBSTRATE: Mineral - Humus WOODY SUBSTRATE: Conifer - Deciduous
WOOD SPECIES: _____ HOW DECAYED: _____ OTHER SUBSTRATE: _____

Ecology

LOCATION/GPS: _____ LOCALITY: _____ ELEVATION, ASPECT: _____
CLIMATE: _____ RECENT WEATHER: _____ AIR TEMP./HUMIDITY: _____

Specimen Sketch

HABITAT: Conifer forest - Deciduous forest - Mixed forest - Bog - Riparian Meadow - Pasture - Lawn - Landscaping - Desert - Bare soil - Burn - Other
SOIL TYPE(S): _____ SOIL TEMP./MOISTURE: _____
HABITAT AGE: _____ PREVALENT PLANTS: _____

Microsopic Characteristics

SPORE COLOR: _____ SPORE ORNAMENTATION: _____
SPORES AMYLOID: N - Y SPORE SIZE & SHAPE: _____
CYSTIDIA: N - Y CYSTIDIA TYPES(S) & SIZE : _____
ASCI: Operculate - Inoperculate CLAMP CONNECTIONS: N - Y
HYPHAL TYPES: Generative - Binding - Skeletal
GILL TRAMA: Divergent - Parallel - Convergent

Survey and Manage Description Form – Lichens

General Characteristics

General substrate: Soil - Tree - Rock
Photobiont: Cyanobacteria - Algae - Both
Morphotype: Crustose - Foliose - Fruticose - Squamulose
Lichen prevalence: Scarce - Occasional - Common - Abundant

Ecology

Habitat: _____ Habitat age: _____
Prevalent plants: _____

Cortex Chemistry

K: _____ KC: _____ C: _____ P: _____ UV: _____

Medulla Chemistry

K: _____ KC: _____ C: _____ P: _____ UV: _____

If Crustose

Color: _____ Substrate type: _____
(draw cortex texture, cracks, areoles, apothecia, and thallus margin.)

If Foliose (lobe info)

Width at tip: _____ Hollow: N - Y
Upper surface color: _____
Lower surface color: _____
(draw lobe shape and surface features [both sides]: maculae, tomentum, pruina, pseudocyphellae, rhizines, cilia, apothecia, and propagules)

If Fruticose (branch info)

Avg. length: _____ Color: _____
Central cord: N - Y
(draw branches from attachment to branch tip, noting surface texture, pseudocyphellae, fibrils, podetia, squamules, apothecia, propagules)

If Squamulose

Avg. length: _____ Color: _____
Podetia present: N - Y
(draw squamules and dimensions and location of reproductive features)

Sexual Reproduction

Sexual body: None - Perithecia - Mushroom - Apothecia
Spore size: _____ Spore color: _____
Number of spores/ascus: _____ *(draw cross-section)*

Apothecia Characteristics (if present)

Rim color: _____ Photobiont in rim: N - Y
Disc color: _____ Epihymenium color: _____
Hyopthecium color: _____
Epihymenium response to K: _____

Asexual Reproduction

Asexual propagules: None - Soredia - Isidia - Phyllidia
Location on thallus: Margins - Center - Diffuse
Pycnidia present: N - Y Conidia size: _____

Taxon: _____
Date: _____
Location/GPS: _____
Collector(s): _____
Collection number: _____
Photo Number(s): _____

Thallus Sketch

Sexual Structure ***Spore Sketch***

Asexual Propagules

Pycnidia and Conidia

Taxon: Date:
Collector(s): Coll.#:
State/Prov.: County: Photo#:
Location:
GPS:
Substrate: Wood - Moss - Litter - Soil - Fungus - Other
Habitat:
Notes (*color, taste, odor, shape, etc.*):

Taxon: Date:
Collector(s): Coll.#:
State/Prov.: County: Photo#:
Location:
GPS:
Substrate: Wood - Moss - Litter - Soil - Fungus - Other
Habitat:
Notes (*color, taste, odor, shape, etc.*):

Taxon: Date:
Collector(s): Coll.#:
State/Prov.: County: Photo#:
Location:
GPS:
Substrate: Wood - Moss - Litter - Soil - Fungus - Other
Habitat:
Notes (*color, taste, odor, shape, etc.*):

Taxon: Date:
Collector(s): Coll.#:
State/Prov.: County: Photo#:
Location:
GPS:
Substrate: Wood - Moss - Litter - Soil - Fungus - Other
Habitat:
Notes (*color, taste, odor, shape, etc.*):

Taxon: Date:
Collector(s): Coll.#:
State/Prov.: County: Photo#:
Location:
GPS:
Substrate: Wood - Moss - Litter - Soil - Fungus - Other
Habitat:
Notes (*color, taste, odor, shape, etc.*):

Taxon: Date:
Collector(s): Coll.#:
State/Prov.: County: Photo#:
Location:
GPS:
Substrate: Wood - Moss - Litter - Soil - Fungus - Other
Habitat:
Notes (*color, taste, odor, shape, etc.*):

Taxon: Date:
Collector(s): Coll.#:
State/Prov.: County: Photo#:
Location:
GPS:
Substrate: Wood - Moss - Litter - Soil - Fungus - Other
Habitat:
Notes (*color, taste, odor, shape, etc.*):

Taxon: Date:
Collector(s): Coll.#:
State/Prov.: County: Photo#:
Location:
GPS:
Substrate: Wood - Moss - Litter - Soil - Fungus - Other
Habitat:
Notes (*color, taste, odor, shape, etc.*):

Taxon: Date:
Collector(s): Coll.#:
State/Prov.: County: Photo#:
Location:
GPS:
Substrate: Wood - Moss - Litter - Soil - Fungus - Other
Habitat:
Notes (*color, taste, odor, shape, etc.*):

Taxon: Date:
Collector(s): Coll.#:
State/Prov.: County: Photo#:
Location:
GPS:
Substrate: Wood - Moss - Litter - Soil - Fungus - Other
Habitat:
Notes (*color, taste, odor, shape, etc.*):

Appendix B

Endangered Fungi

The US Fish & Wildlife Service considers the following lichens as endangered:

- *Gymnoderma lineare*
- *Cladonia perforata*

The International Union for Conservation of Nature (IUCN) considers the following fungi and lichens as threatened or endangered:

- *Anzia centrifuga*
- *Cladonia perforate*
- *Erioderma pedicellatum*
- *Gymnoderma insulare*
- *Pleurotus nebrodensis*

The following species are listed on Mushroomobserver.org as "Rare, Threatened, and Endangered Mushrooms":

- *Bridgeoporus nobilissimus*
- *Cantharocybe gruberi*
- *Chorioactis geaster*
- *Clavariadelphus pistillaris*
- *Erioderma pedicellatum*
- *Fomitopsis officinalis*
- *Galerina steglichii*
- *Gyroporus cyanescens*
- *Hapalopilus croceus*
- *Hericium coralloides*
- *Hypocreopsis lichenoides*
- *Ionomidotis irregularis*
- *Mutinus ravenelii*
- *Pleurotus nebrodensis*
- *Podofomes trogii*
- *Polyporoletus sublividus*
- *Polyporus umbellatus*
- *Psilocybe graveolens*
- *Sparassis crispa*
- *Underwoodia columnaris*
- *Zeus olympius*

The following 33 fungal species are threatened in Europe:

- *Amanita friabilis*
- *Amylocystis lapponica*
- *Antrodia albobrunnea*
- *Armillaria ectypa*
- *Boletopsis grisea*
- *Boletus dupainii*
- *Bovista paludosa*
- *Cantharellus melanoxeros*
- *Cortinarius ionochlorus*
- *Entoloma bloxamii*
- *Geoglossum atropurpureum*
- *Gomphus clavatus*
- *Hapalopilus croceus*
- *Haploporus odorus*
- *Hericium erinaceus*
- *Hohenbuehelia culmicola*
- *Hygrocybe calyptriformis*
- *Hygrophorus purpurascens*
- *Laricifomes officinalis*
- *Leucopaxillus compactus*

- *Lyophyllum favrei*
- *Myriostoma coliforme*
- *Phylloporus pelletieri*
- *Podoscypha multizonata*
- *Pycnoporellus alboluteus*
- *Sarcodon fuligineoviolaceus*
- *Sarcosoma globosum*
- *Sarcosphaera coronaria*
- *Skeletocutis odora*
- *Suillus sibiricus*
- *Torrendia pulchella*
- *Tricholoma colossus*
- *Tulostoma niveum*

The website www.cybertruffle.org is working with the IUCN to determine which of 1,005 micro fungi should be placed on protection "red lists." Of these, only the following species from the Ascomycota have been proposed:

Diaporthales

- *Leucostoma cinctum*
- *Leucostoma niveum*
- *Leucostoma persoonii*
- *Valsa ambiens*
- *Valsa ceratosperma*
- *Valsa cypri*
- *Valsa malicola*
- *Valsa salicina*
- *Valsa sordida*

Elaphomycetales

- *Elaphomyces muricatus*

Helotiales

- *Cyttaria berteroi*
- *Cyttaria darwinii*
- *Cyttaria espinosae*
- *Cyttaria exigua*
- *Cyttaria hookeri*
- *Cyttaria johowii*
- *Didymascella thujina*
- *Lachnellula occidentalis*
- *Lachnellula pini*
- *Lachnellula subtilissima*
- *Lachnellula suecica*
- *Lachnellula wilkommii*
- *Phacidium lacerum*

Hypocreales

- *Ascopolyporus polychrous*

Mycosphaerellales

- *Septoria antirrhini*
- *Septoria cirsii*
- *Septoria cornicola*
- *Septoria geranii*
- *Septoria lamiicola*
- *Septoria pistaciae*
- *Septoria rhamni catharticae*
- *Septoria pistaciae*
- *Septoria rhamni-catharticae*
- *Septoria sisymbrii*
- *Septoria urticae*
- *Septoria verbascicola*

Pezizales

- *Gyromitra esculenta*
- *Tuber aestivum*
- *Tuber melanosporum*

Rhytismatales

- *Ascodichaena rugosa*
- *Colpoma ledi*
- *Cryptomyces maximus*
- *Cryptomycina pteridis*
- *Cyclaneusma niveum*
- *Hypohelion scirpinum*
- *Lophodermella conjuncta*
- *Lophodermium agathidis*
- *Lophodermium neesii*
- *Lophodermium platyplacum*
- *Lophomerum rhododendri*
- *Marthamyces emarginatus*
- *Rhabdocline pseudotsugae*
- *Rhytisma salicinum*
- *Zeus olympius*

Taphrinales

- *Taphrina deformans*

Xylariales

- *Diatrype bullata*
- *Diatrype disciformis*
- *Diatrype stigma*
- *Xylaria hypoxylon*
- *Xylaria polymorpha*

Hyphomycetes

- *Slimacomyces monosporus*

In Oregon and Washington, the US Interagency Special Status/Sensitive Species Program (ISSSSP) lists the following as rare or threatened species that may be protected on a case-by-case basis. Similar organizations may exist in your area.

Mushrooms

- *Albatrellus avellaneus*
- *Albatrellus ellisii*
- *Alpova alexsmithii*
- *Amanita armillariiformis*
- *Amanita malheurensis*
- *Arcangeliella camphorata*
- *Arrhenia lobata*
- *Boletus pulcherrimus*
- *Bridgeoporus nobilissimus*
- *Chamonixia caespitosa*
- *Choiromyces venosus*
- *Cortinarius barlowensis*
- *Craterellus tubaeformis*
- *Cystangium idahoensis*
- *Dermocybe humboldtensis*
- *Galerina atkinsoniana*
- *Gastroboletus vividus*
- *Gymnomyces fragrans*
- *Helvella crassitunicata*
- *Hydnotrya michaelis*
- *Hygrophorus caeruleus*
- *Macowanites mollis*
- *Mythicomyces corneipes*
- *Phaeocollybia californica*
- *Phaeocollybia gregaria*
- *Phaeocollybia oregonensis*
- *Pseudorhizina californica*
- *Ramaria amyloidea*
- *Ramaria rubella var. blanda*
- *Rhizopogon bacillisporus*
- *Rhizipogon brunneifibrillosus*
- *Rhizipogon chamaleontinus*
- *Rhizipogon ellipsosporus*
- *Rhizipogon exiguus*
- *Rhizopogon inquinatus*
- *Rhizopogon quercicola*
- *Rhizopogon rogersii*
- *Rhizopogon semireticulatus*
- *Rhizopogon subclavitisporus*
- *Rhizopogon subradicatus*
- *Stagnicola perplexa*
- *Thaxterogaster pavelekii*

Lichens

- *Anaptychia crinalis*
- *Bryoria bicolor*
- *Bryoria pseudocapillaris*
- *Bryoria spiralifera*
- *Bryoria subcana*
- *Buellia oidelea*
- *Calicium abietinum*
- *Calicium adspersum*
- *Calicium quercinum*
- *Caloplaca stantonii*
- *Cetrelia cetrarioides*
- *Chaenotheca chrysocephala*
- *Chaenotheca ferruginea*
- *Chaenotheca furfuracea*
- *Chaenotheca subroscida*
- *Chaenothecopsis pusilla*
- *Cladidium bolanderi*
- *Cladonia norvegica*
- *Collema curtisporum*
- *Collema nigrescens*
- *Collema undulatum*
- *Dendriscocaulon intricatulum*
- *Dermatocarpon meiophyllizum*
- *Erioderma sorediatum*
- *Fuscopannaria saubinetii*
- *Heterodermia japonica*
- *Heterodermia leucomelos*
- *Heterodermia sitchensis*
- *Hypogymnia duplicata*
- *Hypogymnia pulverata*
- *Hypogymnia subphysodes*
- *Hypotrachyna revoluta*
- *Hypotrachyna riparia*
- *Lecanora caesiorubella subsp. merrillii*
- *Lecanora pringlei*
- *Leioderma sorediatum*
- *Leptogium burnetiae*
- *Leptogium cyanescens*
- *Leptogium platynum*
- *Leptogium plicatile*
- *Leptogium rivale*
- *Leptogium siskiyouensis*
- *Leptogium teretiusculum*
- *Lobaria linita*
- *Microcalicium arenarium*
- *Nephroma bellum*

- *Nephroma occultum*
- *Niebla cephalota*
- *Ochrolechia subplicans*
- *Pannaria rubiginella*
- *Pannaria rubiginosa*
- *Peltigera pacifica*
- *Peltula euploca*
- *Pilophorus nigricaulis*
- *Platismatia lacunosa*
- *Pseudocyphellaria mallota*
- *Pseudocyphellaria rainierensis*
- *Ramalina pollinaria*
- *Schaeraria dolodes*
- *Sigridea californica*
- *Stenocybe clavata*
- *Stereocaulon spathuliferum*
- *Sticta arctica*
- *Telocshistes flavicans*
- *Texosporium sancti-jacobi*
- *Thelenella muscorum var. octospora*
- *Thelomma mammosum*
- *Tholurna dissimilis*
- *Umbilicaria hirsuta*
- *Usnea lambii*
- *Usnea longissima*
- *Usnea nidulans*
- *Usnea rubicunda*
- *Vezdaea stipitata*

Appendix C

Fungal Toxins

As the grand chemists of Nature, fungi produce an incredible array of complex compounds. Many are potent medicines, while others are harmful toxins. The following are the most notable classes of nauseating, harmful, and/or lethal substances that fungi produce.

Amatoxins

- *Amanita bisporigera*
- *A. phalloides*
- *A. verna*
- *A. virosa*
- *Conocybe filaris*
- *C. rugosa*
- *Galerina marginata* (*G. autumnalis*)
- *G. fasciculata*
- *G. sulciceps*
- *G. venenata*
- *Hypholoma fasiculare*
- *Lepiota brunneoincarnata*
- *L. castanea*
- *L. citrophylla*
- *L. felina*
- *L. helveola*
- *L. josserandii*
- *L. subincarnata*

Amatoxins are by far the most concerning to foragers as they are responsible for the greatest number of lethal human mushroom poisonings in North America. Amatoxins are cyclopeptides (i.e. small, eight amino acid proteins with ring structures) that are divided into two categories. The first group includes seven phallotoxins which, while quite toxic, are not as concerning to the casual hunter as they do not seem to be absorbed by the intestines.

The other, more deadly amatoxins are the *amanitins*. These compounds inhibit RNA transcriptase, essentially halting protein production and cellular functioning in the body. With an LD_{50} of 6 milligrams, amanitins are extremely toxic in low doses. Less than 50 grams of *Amanita phalloides* (approximately one medium-sized mushroom) is enough to kill a human. Even the spores of these fungi can be poisonous. The effects of amanitins often develop in the following four stages:

1. Six to 24 hours after ingestion the toxins begin to actively destroy the victim's kidneys and liver, though no discomfort is experienced.
2. After 24 hours, violent vomiting, bloody diarrhea, and severe abdominal cramps begin.
3. After this initial period of pain, symptoms subside for 24 hours.
4. A relapse then occurs in which the kidneys and liver start to fail, potentially leading to coma and/or death. Patients may also "bleed out" and die due to the destruction of clotting factors in their blood. If this stage does not prove to be fatal, excruciating relapses may occur for 10–20 days.

In the event of amanitin poisoning, Robert Rogers suggests the victim drink a glass of salt water every half hour until they get to a hospital. While historically antibiotics and other odd medications have been administered in an attempt to treat amatoxin poisoning, some hospitals are beginning to adopt protocols that incorporate silibinin, an extract of Milk Thistle (*Silybum marianum*) seeds. This natural hepatoprotectant herb can be quite effective at treating amanitin poisonings, so much so that it was approved for this purpose in Germany in 1984. If administered intravenously within 78 hours, silibinin can potentially produce a full recovery from poisonings, even in elderly patients. Still, the body should be well treated to ensure healing is complete in the weeks that follow. Robert Rogers suggests restoring kidney function with daily consumption of 300 milligrams of alpha lipoic acid along with Reishi decoctions.[1]

Gyromitrin

- *Cudonia circinans*
- *Gyromitra ambigua*
- *G. ambigua*
- *G. californica*
- *G. caroliniana*
- *G. esculenta*
- *G. fastigiata*
- *G. gigas*
- *G. infula*
- *G. korfii*
- *G. sphaerospora*

Gyromitrin readily converts to monomethylhydrazine (MMH), a component of some rocket fuels used for space travel. Two to twenty-five hours following consumption, the typical symptoms set in as abdominal pain, diarrhea, vomiting, coma, convulsions, delirium, fever, headache, restlessness, respiratory failure, liver damage, and jaundice. In the 7 days following consumption, a 15-35% chance of death is possible due to MMH disrupting the function of vitamin B_6, and ultimately causing kidney, liver, or heart failure. Gyromitrin can be cooked off via parboiling. However, as it is quite volatile, this should be done outdoors or in a very well-ventilated area. Personally, I don't risk it.

Orellanine (Cortinarin A and B)

- *Cortinarius gentilis*
- *C. orellanoides*
- *C. orellanus*
- *C. rubellus*
- *C. speciosissimus*
- *C. splendens*

This compound can cause delayed renal failure 36 hours–3 weeks(!) after ingestion. Symptoms include insatiable thirst, frequent urination, nausea, vomiting, lethargy, headaches, shivering without a fever, and liver damage. Fifteen percent of cases prove to be fatal as there is no known treatment. Supposedly, no *Cortinarius* species containing these compounds are known in North America. However, it is recommended to avoid consuming any *Cortinarius* mushroom that is not known to be safe.

Paxillus Syndrome

Caused mainly by *Paxillus involutus*, this syndrome is a potentially fatal immune response in which red blood cells begin to breakdown. Symptoms are not immediate and may only display after years of consuming this mushroom—a delay that often causes a misdiagnosis of idiopathic immune hemolytic anemia.

Coprine

Found primarily in *Coprinus atramentarius*, this compound has a similar effect on the human body as Antabuse, the drug used to discourage relapses in alcoholics. Normally, alcohol is converted to acetaldehyde in the body and then to acetate and CO_2. Coprine blocks the second step in this process, creating a buildup of acetaldehyde in the body. The effects from this buildup include tingling in the arms and legs, sweating, headache, anxiety, confusion, headache, fainting, dizziness, confusion, vomiting, and a rapid heartbeat. Effects tend to show up 30 minutes after drinking alcohol and last for two to four hours. Interestingly, the effects of coprine can occur up to 5 days after eating these mushrooms!

Other

The following species are known to cause mild to severe gastrointestinal (GI) distress in many individuals:

- *Agaricus californicus*
- *A. hondensis*
- *A. placomyces*
- *A. praeclaresquamosus*
- *A. xanthodermus*
- *Boletus satanas*
- *B. erythropus*
- *B. haematinus*
- *B. pulcherrius*
- *B. subvelutipes*
- *Chlorophyllum molybdites*
- *Entoloma spp.*
- *Gomphus floccosus*
- *Hebeloma spp.*
- *Lactarius spp.*
- *Hypholoma fasiculare*
- *Omphalotus spp.*
- *Tricholoma spp.*

The following popular edibles are known to cause GI distress in some people:

- *Armillaria spp.*
- *Calvatia gigantea*
- *Laetiporus spp.*
- *Lepiota naucina*
- *L. rachodes*
- *Morchella elata*
- *Suillus luteus*
- *Megacollybia platyphylla*

Mycotoxins

Aspergillus flavus and *A. parasiticus* produce a range of compounds that commonly contaminate food crops. These include fumonisin, zearalenone, ochratoxin, and aflatoxins. These last compounds are some of the most carcinogenic compounds known in the world. These fungi commonly grow on stored grains and beans, making these toxins quite common in many food ingredients, including coffee and processed food products. The best option for reducing the impacts of mycotoxins is to ferment foods[2] and to regularly detoxify one's body.

In the Event of Poisoning

If you or someone you know has potentially consumed a poisonous mushroom, do not risk your health by "waiting it out." Seek help immediately. Contact a physician or your local poison control center and get the suspect mushroom positively identified. If the mushroom is still available, bring it with you to the hospital along with your collection notes and photographs to ensure identification by an expert mycologist. Mushrooms collected from lawns, roadsides, or industrial areas may be contaminated by pesticides or heavy metals. After the incident, submit a report to the North American Mycological Association's Poison Case Registry.[3]

Appendix D

Fungal Dyes and Paper

Since Neolithic times, humans have worked with plants, minerals, invertebrates, insects, and lichens as sources for pigments and fabric dyes. Mushroom-based dyes, however, are surprisingly missing from written and archeological accounts. In the latter half of the 20th century, Miriam Rice helped establish the art of mushroom dye and papermaking and formed the International Mushroom Dye Institute. The following dye and paper making processes are inspired by her foundational work.

Mushroom Dyes

Materials

- Stainless steel or enamel pot dedicated to dyeing
- Castile soap and/or Fels Naptha™
- 8 ounces of wool
- Water
- Mushrooms
- Alum and cream of tartar
- *OR* Ferrous sulfate, cream of tartar, and Gauber's salt
- *OR* Fermented urine

Method

1. Work outside or in a well-ventilated area.
2. Gently wash the wool using a few drops of soap in tepid water. To avoid felting, do not agitate the wool or change the water temperature rapidly. If working with commercial wool, use Fels Naptha™ to remove any chemicals that can interfere with the dyeing process.
3. Warm 5 quarts (5 L) of water to 110°F (43°C).
4. Add 10 teaspoons alum and 2 teaspoons cream of tartar *OR* 4.5 teaspoons ferrous sulfate, 2 teaspoons cream of tartar, and 4 tablespoons Glauber's salt *OR* fermented urine. These substances are mordants that help fix colors to the wool so they don't fade in the sun or wash out easily. Alum (potassium aluminum sulfate) and Iron (ferrous sulfate *or* copperas) mordants are the safest for mushroom dyeing. Soak the fabric in a mordant bath for an hour before dyeing. Different mordants produce different colors from the same mushroom species.
5. Once the salts are dissolved, add the warm, wet, and freshly washed wool.
6. Simmer the wool in the mordant bath at 195°F (90°C) for 30–45 minutes.
7. Allow wool to cool in the mordant bath for 20 minutes.
8. If the mordanted wool will not be used right away, it can be stored wet in plastic bags for 6–8 days.

9. Cut the mushrooms into small pieces, soak them in water (enough to submerge your fabric), heat, and simmer for a few hours. Two parts fungus to one part wool is a good starting ratio. Different species release their pigments at different rates. In general, the firmer the fungus, the longer it takes to coax out its color.
10. Allow the dye bath to cool so as to prevent felting.
11. Strain out the mushroom chunks and use them for papermaking.
12. Place the mordanted fabric into the dye bath solution and return to heat. Gently add the wool to the dye liquid and completely submerge it. Multiple pieces of fabric should be added in unison to ensure even dyeing.
13. Warm the water back up and allow the wool and dye to mingle until the color is satisfactory. Cool the water before removing the fabric. If time is not a concern, allow them to cool in the pot overnight.
14. The first batch of fabric will take up as much of the dye as it can. By repeating steps 12–13, the remaining pigment can be used to dye more fabric, though the color may be lighter.
15. Rinse the wool in warm water using a few drops of soap and minimal agitation.
16. To enhance blues, soak the dyed yarn in a pH 10 solution made with water and washing soda. To increase fastness and/or potentially change the color of the dye, soak the fabric in a pH 3–5 bath made with tepid vinegar and water.
17. Rinse the fabric and hang to dry.

Other fabrics and materials can be dyed as well, though wool tends to take to dyes the best. For non-fabric items, boil the object for several hours prior to dyeing.

Mushroom Paper

After making dyes from mushrooms, the remaining tissue can be pulped to make paper of various colors and textures.

Materials

- Blender or food processor (preferably industrial strength)
- Knife
- Paper making mold and deckle
- Pieces of muslin slightly bigger than the mold and deckle
- Rolling pin
- Shallow tub or basin
- Sheets of newspaper
- Sledgehammer
- Fungus (see chart for options)

Method

1. If the mushroom is very hard, tenderize it with 10–20 hits from a sledgehammer, soak it in water for several hours or days, and then repeat. Changing soaking water tends to produce a whiter and finer textured paper.
2. Chop the mushroom into small pieces, if possible.
3. Pulp the chunks in a blender with water. Try to blend them until all the chunks are gone. This may take a while. Don't burn out the blender motor!
4. Pour the pulp into a shallow tray and add more water. The more water you add, the more dispersed the fibers will be and the thinner your final paper will be. Experiment to find the right density. For non-woody mushrooms, mix in a binder such as *Pseudohydnum gelatinosum*, corn starch, or gelatin. Calcium carbonate powder can also be added to increase opacity.
5. Place muslin between the mold and deckle and dip the sandwich into the pulp slurry. Angle the mold and scoop it up level to create a consistent thickness in the

paper. Moving the screen side to side in the water helps disperse the fibers evenly.

6. Remove the mold to reveal the sheet of paper. Invert the deckle and muslin carefully onto a piece of newspaper.
7. Run a rolling pin across the backside of the muslin to flatten the paper and remove extra moisture.
8. Remove the piece of muslin from the paper carefully.
9. Lay the sheet between several layers of newspaper and let it dry. Continue to dry the mushroom paper by replacing newspapers. Ironing gently over a covering piece of cloth can speed up this process. When dry enough to be easily handled, hang the paper to dry or, if you want very flat paper, put it under heavy books or other weights. Any leftover slurry can be dried and the pulp stored for later rehydration and use.
10. Make stuff! Try adding spores from spore prints to ink and writing with the mixture. The paper can also molded into shapes.

Lichen Dyes

Fabric (after being treated as in step 2 for mushroom dyes), is dyed with lichens in three ways:

Boiling Water Method (BWM)

Obtains yellow, orange, and brown colors. Here, 2 cups (500 mL) of lichen material are boiled for 30 minutes and then simmered for 60 minutes at 190°F (88°C). The liquid is retrieved and the process repeated with the same material two more times. One ounce of fabric and 0.5 cups (125 mL) of salt are then simmered in the liquid for 2–4 hours. The fabric is then allowed to cool in the bath and sit for at least 24 hours. Finally, the fabric is strained and the liquid retrieved to dye more fabric.

Ammonia Method (AM)

Obtains red, maroon, and purple pigments. In a large jar, a cup (250 mL) of lichens are covered with 0.5 cups (150 mL) household ammonia and 0.5 cups (150 mL) water. The jar is shaken vigorously every day for several weeks (for erythrin-containing lichens, 3 weeks; for lecanoric acid lichens, 6-8 weeks; and for gyrophoric acid lichens, at least 16 weeks) until the mix turns to a dark magenta. The resulting liquid is diluted 1:16 with water and mixed 1:2 with salt (dye:salt). Fabric is added to the mix and warmed to 180°F (82°C) for 10 minutes, cooled to 160°F (70°C) for one hour, then allowed to cool and soak overnight. The next day, the fabric and bath are reheated to 160°F (70°C) for an hour, then left to cool and soak for another 24 hours. Adding vinegar to the dye bath to obtain a pH of 4–7 will create a more red dye, adding additional ammonia to obtain a pH of 8–11 will create a more purple color.

Photo-Oxidation Method (POD)

Often used with *Candelaria* and *Xanthoria spp.* (abundant in suburbs and agricultural areas) to obtain blue dyes. In a large, sealed jar, 1 cup (250 mL) lichen material and 0.5 cups (125 mL) ammonia are shaken and allowed to sit for several days. One and a half cups (375 mL) of water is then vigorously stirred in. The jar is then sealed and allowed to sit for 9–12 weeks. One ounce of fabric is then heated in the dye water to 180°F (82°C) for 20 minutes, allowed to sit until pink (1–2 hours), then wrung out and placed in direct sunlight. With constant turning, the fabric will turn blue. If it doesn't, it is rewetted in the dye water.

Mushroom Paper and Dyes Chart

A – Alum mordant used
I – Iron mordant used
N – No mordant used

Numbers correspond to the pH of the dye bath.

Mushroom Paper And Dye Colors

	Paper Color											Dye Color							
	Lt Brown	Med Brown	Dk Brown	Lt Yellow	Gold-Brown	Dk Red	Lt Red	Lt Pink	Orange	White	Beige	Yellow	Orange	Red/Pink	Purple	Lavendar	Blue	Green	Brown
Agaricus augustus	•																		
Agaricus spp.																			I
Albatrellus flettii					•														
Amanita muscaria				•															
Astraeus pteridis																			Y
Boletopsis subsquamosus					•														
Boletus aereus												A - Tubes only							
Boletus edulis												A - Tubes only							
Bulgaria inquinans																			A
Calvatia gigantea					•														
Cantharellus infundibuliformis					•														
Chroogomphus vinicolor			•											A					
Clavaria truncata																I			
Coprinus atratomentosus	•																		
Cortinarius violaceus																N - 10			
Cryptoporus volvatus					•														
Daedalea quercina					•														
Democybe austrosanguinea													A	Shades vary with pH					
Democybe californica													A / I	N					
Democybe cinnabarina													N / A - 4						
Democybe croceofolia													A - 4						
Democybe erythocephala													A - 4	Shades vary with pH					
Democybe malicoria													A - 4						
Democybe sanguinea							•							N / A - Varies with pH					
Democybe splendida													N / A	Shades vary with pH					
Dermocybe cinnamomea						•							N / A / I - 4						
Dermocybe crocea												A							
Dermocybe phoenicea								•						A - Shades vary with pH					
Dermocybe semisanguinea														A - Shades vary with pH					
Echinodontium tinctorium						•							N / A						
Fistulina hepatica					•														
Fomes fomentarius																			I
Fomitopsis cajanderi							•												N
Fomitopsis officinalis				•															
Fomitopsis pinicola	•																		
Ganoderma applanatum							•												Y
Ganoderma lucidum				•															
Gautieria monticola															I				
Gomphidius glutinosus																			A
Gomphus clavatus															I	I			
Gomphus floccosus															I				
Gymnopilus liquirtae												None, Alum							
Gymnopilus luteofolius												N / A							

Mushroom Paper And Dye Colors

	Paper Color											Dye Color							
	Lt Brown	Med Brown	Dk Brown	Lt Yellow	Gold-Brown	Dk Red	Lt Red	Lt Pink	Orange	White	Beige	Yellow	Orange	Red/Pink	Purple	Lavendar	Blue	Green	Brown
Gymnopilus penetrans												N/A							
Gymnopilus spectabilis		•										N/A							
Gyromitra infula													A						
Hapalopilus nidulans															A-9	N			
Hydnellum aurantiacum																		I	
Hydnellum peckii			•																N
Hydnellum scrobiculatum																			N
Hydnellum zonatum																			A
Hygrocybe ceracea												N/A							
Hygrocybe coccinea												A							
Hygrocybe miniata												A							
Hygrophorus eburneus				•															
Hygrophorus puniceus				•															
Hypholoma aurantiacum												N/A							
Hypholoma fasciculare												A							
Hypomyces lactifluorum													N/A/I						
Inonotus dryadeus											•								
Inonotus hispidus												N/A							
Inonotus tomentosus												N/A							
Laccaria laccata		•																	
Laetiporus sulphureus				•															I
Lenzites betulina				•															I
Omphalotus olivascens			•																
Omphalotus olivascens															A	N		I	
Phaeolus schweinitzii			•									N							I
Phellinus pini					•														
Phellinus spp.												N/A							
Phellodon niger																		N/A/I	
Phellodon tomentosus																		I	
Pholiota kauffmanii												N/A							
Piptoporus betulinus																			
Pisolithus tinctorius			•																
Polyporus tomentosus																			N
Pulveroboletus spp.												None, Alum							
Pycnoporellus alboluteus				•															
Pycnoporellus fulgens				•									A						
Pycnoporellus rutilans									•										
Pycnoporus cinnabarinus													A						
Ramaria apiculata															I				
Ramaria formosa					•										I				
Rhizopogon spp.																			N
Russula fragrantissima					•														
Russula spp.				•															

Mushroom Paper And Dye Colors

	Paper Color											Dye Color							
	Lt Brown	Med Brown	Dk Brown	Lt Yellow	Gold-Brown	Dk Red	Lt Red	Lt Pink	Orange	White	Beige	Yellow	Orange	Red/Pink	Purple	Lavendar	Blue	Green	Brown
Sarcodon fennicus																			A
Sarcodon imbricatus			•																
Schizophyllum commune	•																		
Stereum hirsutum										•									
Suillus brevipes	•																		
Suillus spp.												N / A							
Tapinella atrotomentosa															A		Y	I	
Thelephora palmata																	Y		
Thelephora terrestris																	Y		
Trametes versicolor											•								
Tricholomopsis rutilans																			A
Tyromyces chioneus										•									

Chemical Spot Test	Lichen Acid	Dye Process	Color	Typical species
K+ yellow (surface of white colored lichens)	Atranorin	BWM	Yellow/orange/brown	*Physcia spp.*, many *Heterodermia spp.* and *Platismatia spp.*
K+ bright yellow (medulla of various colored lichens)	Lobaric acid	BWM	Yellow/orange/brown	Many *Stereocaulon spp.*
K+ pale yellow (surface of pale green lichens)	Usnic acid	BWM	Yellow/orange/brown	*Usnea spp.*, *Ramalina spp.* are most likely to have usnic acid by itself
K+ blood-red to purple (surface of yellow colored lichens)	Parietin	POD	Blue	*Xanthoria spp.*, *Xanthomendoza spp.*
C+ red (medulla)	Erythrin	AM (3 week shake)	Red/purple	*Diploschistes spp.*
C+ red, K+muddy brownish-pink (medulla)	Fumarprotocetraric acid	AM	Red/purple	Some *Cetraria spp.*, *Cladonia spp.*, *Bryoria spp.*, *Melanohalea spp.*
C+ red (medulla)	Gyrophoric acid	AM (16 week shake)	Red/purple	*Lasalia spp.*, most *Ochrolechia spp.*, most *Umbilicaria spp.*
C+ red, KC+ red (medulla)	Lecanoric acid	AM (6–8 week shake)	Red/purple	*Flavopunctelia spp.*, *Hypocenomyces scalaris*, *Melanelixia spp.*, *Parmelina spp.*, *Parmotrema tinctorum*, *Pseudevernia spp.*, most *Punctelia spp.*

Dye-Producing Chemicals in Lichens Chart

***AM** – Ammonia method*
***BWM** – Boiling water method*
***POD** – Polarized ammonia method*

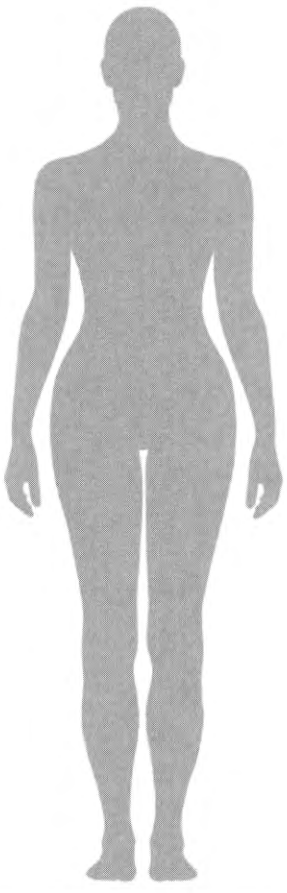
The best way to go about making lichen dyes is to romp around your neighborhood and find which lichens are the most abundant in disturbed areas like the edges of parking lots, on fallen branches of street trees, on firewood, roofs, road construction areas, and recently felled trees, or on concrete walls. Then do some chemical spot tests on these lichens. If the cortex or medulla is K+ yellow, it will produce colors of yellow-orange-brown using the boiling water method; if the lichen is K+ purple, it will make a blue dye using the photo-oxidation method; and if the medulla is C+ reddish, it will create red-purples using the ammonia method. Different lichens can be used together for varying effects, and layering colors can create other colors. For example, dyeing a fiber in a blue POD bath, letting it dry, then dyeing this fiber in a yellow BWM bath can create a lovely green fiber.

For more details on dyeing with lichens, recipes, the history of lichen dyes, and altering color using pH or household mordants like onion skins, rhubarb, or urine and everything else about lichen dyeing, see *Lichen Dyes: The New Source Book* by Karen Diadick Casselman.

Appendix E

Mycelial Healing Exercises

By Mara Fae Penfil



Template Silhouette

The Mycelial Mat of Healing

As you think, so shall you become. —Anonymous

Beyond embracing the natural abilities of fungi, plants, or other organisms to remove pollution in the environment, it is important that we (as active human contributors to pollution) learn how to heal our own toxic environments, whether they be emotional, spiritual, or physical.

The Mycelial Mat of Healing is an activity that utilizes mycelium as a model to teach us how to map toxicity within our own bodies and transform it into nutrition that helps us grow. In effect, this activity has the potential to open up a new way of thinking and exploring your personal healing process.

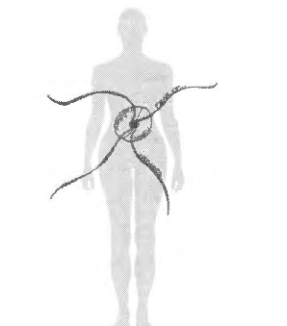
As the healing process is unique to everyone, feel free to adapt the steps listed below to fit your own needs. Likewise, this activity can be done in around 30 minutes, or expanded to an hour or more. The details are all up to you. Most importantly, enjoy the time that you spend with this activity and share it with your community.

Materials

- Colored pens, pencils, or markers
- A print out of the template silhouette. Alternatively, you can draw your own silhouette on any piece of paper.

Setting Your Surroundings

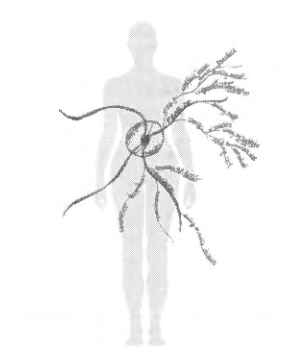
Healing activities work best if you are in an environment that is comforting and feels safe to you. Try to create a space that is grounding and that cultivates a sense of comfort and safety. Choose music that relaxes you, have a cup of water or a warm beverage ready (recommended are healing herbal or mushroom teas), light a candle or dim the lights, and try to engage with this activity during a time when you know you will not be interrupted.



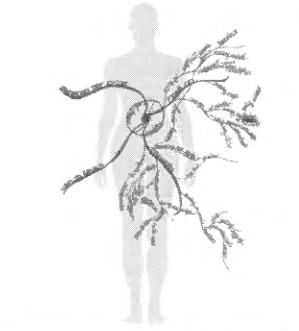
Steps 3–6

Guidelines

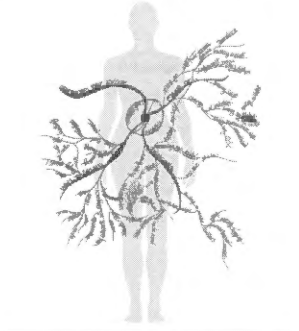
1. Take a few moments to sit with your eyes closed and take several cleansing breaths, inhaling deeply for several seconds and exhaling for just as long.
2. Begin to envision something in your life that you want to transform. (This can be more abstract, such as a feeling or emotion, or it can be more tangible such as a habit, physical pain, attachment to an object or relationship with yourself or others.)



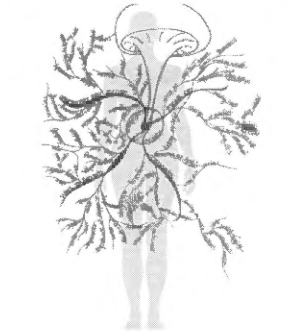
Step 7



Step 9



Step 10



Step 12–13

3. Once you figure out what you want to focus on, draw a circle on the piece of paper labeled with what you want to transform (*negative charge*) on one side of the circle, and what you want it transformed into (*positive charge*) on the opposite side. Draw your circle anywhere on the body, such as the center, the heart, or at the place where you are holding on to your negative charge.
4. Draw your starting point (*mycelial node*) at the center of this circle with 4 main hyphae branching out from it.
5. By the end of this activity, two of these hyphae will represent a broad look at your negative charge (e.g. triggers, past experiences, fears, attachments), and the other two will represent a broad look at your positive charge (e.g. coping skills, your network of support, opportunities, ways to ground).
6. Take a few moments to breathe and reflect on main themes that contribute to your negative charge. When you have decided what two things you want to focus on, label two hyphae with these aspects.
7. For each main hyphae, spend 10–15 minutes branching and mapping your negative charges. Try to uncover all the things that contribute to and support those charges. Start simple and allow yourself to get more detailed if it feels right.
8. Once you are finished mapping your negative charges, take a 5-minute break to breathe, reflect, and ground before moving on to the next step.
9. When you are ready, begin focusing your attention on the positive charges in your life. The goal here is to identify traits that enable you to transform the negative charges into healthy and nurturing ones. These positively-charged hyphae will represent broad ideas and themes. Take your time to label these life-sustaining hyphae.
10. For each main hyphae, spend 10–15 minutes branching and mapping your positive charges. Start simple and allow yourself to get more detailed if it feels right. Remember to think of things that you already do that help you, and also think of new things that you would like to incorporate into your healing practices and into your life. Mapping out your positive charges will help you to identify tangible actions you can do to transform the parts of yourself that you are trying to heal.
11. Once you are finished mapping your positive charges, take a 5-minute break to breathe, reflect, and ground before moving on to the next step.
12. Starting at your mycelial node, take all of the transformative energy that you have been building and fruit a healthy mushroom body to represent your healing self. You can get as creative as you would like here. What colors and patterns represent the healed and healing you?
13. Once you are finished fruiting, you should have an outline of tools that you can refer to whenever you need. As time moves on, you can share these parts of yourself or these tools through your healing, nurturing, and resilient spores.
14. Take a final 5 minutes to breathe, reflect, and ground. Smile and be kind to yourself. Healing takes a lot of energy and it is important to give yourself the time to rest and re-energize.

Mycelial Meditation and Visualization

For the most effective practice, the following visualization meditation should be read aloud by a skilled facilitator. If helpful, it can be recorded for personal and private use only. During this visualization you will have the chance to explore through the lens of fungi how your energy interacts with the world around you. In a space that is safe and relaxing for you, take your time reading through and meditating on each of the following lines.

In a comfortable seated position, or lying down, close your eyes and take a moment to ground. Begin by bringing your attention to your breath. Breathe in deeply and slowly, allowing your stomach to fill up on the inhale. When your breath reaches the back of your throat, pause momentarily. Now exhale slowly, allowing your body to relax with your out breath. Again, breathe in to fill your lungs fully, and breathe out to empty them completely. Take a moment to simply be still in the presence of your breath.

Allow your mind to filter through all the activities from the past few days, acknowledge each thought that arises, and then let them all melt away. Allow your mind to be still. Allow your mind to find a clear space to rest and to be present in this meditation. Continue to focus on your breathing. Take a deep breath in, and open your mouth to exhale. Again, take a deep breath in, and release it with a big open-mouth exhale, clearing any stale air your lungs are still holding on to. Keeping your eyes closed, let your breath return to its natural rhythm.

In your daily walk here on Earth, you are intimately familiar with a duality that is about you; there is the landscape of your inner world, tended to by your many personal thoughts and feelings, and there is what is outside of yourself in the communal world, tended to by the many forces of the universe at large. Between your inner and outer landscapes lies a barrier in which these two worlds meet. This barrier, like that of a cell membrane, is semipermeable, allowing or blocking the flow of various energies between yourself and the world that surrounds you.

Imagine you walk into a kitchen where your favorite home cooked meal is being prepared. How do the fragrances that surround you affect your being? What memories arise from the essence of these smells?

Imagine that you are walking away from a heated conversation with a family member. How has this interaction impacted you and your mood? What feelings and emotions arise for you in this moment?

Imagine that you are standing in a field outside as the first drops of rain begin to fall after several weeks of dry weather. How do you respond to this change? What energy do you emote and give back to the world that nurtures you?

Each and every one of us has our own way of responding to external stimuli such as these. Each one of us allows different pieces of these experiences to penetrate our energy membrane and mend our internal landscapes. Remember to breathe.

Take a moment to reflect: What from the outer environment today has permeated your energy membrane and entered your inner world? How has this passage of energy affected or altered your inner landscape? In exchange, how has this impacted the way in which you interact with the other living organisms and environments that surround you?

As you reflect, expand your vision. Begin to reflect on the interactions between these two worlds over the past week. Begin to reflect on your interactions over the past month. Begin to reflect over the past year. Overall, how would you describe the relationship between your inner and outer worlds?

Now, imagine that your inner world is a large body of mycelium and the energy membrane represents how you interlace and connect with the environment around you.

When you meet at the membrane, are you mycorrhizal in nature, working in tandem with other organisms, sharing nutrients and energy? How have you shared in this way?

Perhaps your world has been filled with things that don't quite serve you. In this case, do you act saprophytically? Do you utilize your energy to transform these things into that which does feed you and, inevitably, other organisms in your environment?

When you feel things outside of yourself that are harming others, do you act like the fungi that bioaccumulate heavy metals into their bodies, accumulating the harm that you see into your body—even with no overt use for it—in an effort to simply help those around you?

Even still, have there been times that you have interacted in a more toxic way, resembling pathogenic or parasitic fungi? Maybe you have gravitated and latched on to someone or something in your life and taken energy even when there was none to give. Maybe you left a space to become more toxic than how it was when you first arrived.

Notice if these reflections have been easy or challenging for you. It can be difficult to recognize in what ways you have perhaps overstepped your boundaries, and it can even be difficult to honor yourself for how well you have done in your life. This sort of hard work, seeing yourself fully and truly for who you are, valuing your shadow and your light, is critical for change and for growing in sync with the world that surrounds you, rather than as a separate, isolated piece of creation.

Take another moment to reflect on how you have chosen to interact with the world around you. Begin to slowly shift your focus to what you feel in your heart center. In this space, become aware of the way you have been interacting with the world—if it is something that feels good for you, if it is something that feels painful for you, or if it is a healthy mixture of emotions.

Take a moment to think about how you would alter your responses to allow for healthier interactions between yourself and the outside world. Also, what behaviors are working that you would continue to practice? This space in your heart center is a space that you can always return to, to check in, to reflect, and to find your truth. It will not lie to you if you listen for its guidance.

Take a deep breath in, filling up your belly, and then your chest, and when you feel the air swirling in the back of your throat, pause momentarily. Now, open your mouth, and let out a deep and gratifying exhale. Again, breathe in, and release with a big exhale. As you begin to bring awareness back into your physical body, I invite you to roll your thumbs over the tips of each one of your fingers, living for just a moment solely in the sensation that this movement brings.

Take a deep breath in. Whether lying down or in your seated position, raise your arms straight over your head and stretch to lengthen your spine. Take a deep breath in, and with your next exhale release your arms by your side. If you are lying down, roll over onto your left side and take a moment to be still in a fetal position. Using your right hand, press into the earth to help you come to a seated position. Keep your eyes closed. Take a deep breath in, open your mouth, and exhale.

Before you fully come out of this meditation, I invite you to take this simple way of looking at the world into your everyday interactions of life, learning how to create a balanced flow between your inner and outer landscapes. Be willing to look deep into yourself and from multiple viewpoints. Be courageous to do the hard work it takes to be an ever present and active part of our interconnected lives and the world that supports us. Grow your mycelial body healthy and strong, fruit a life of hard work and love, and sporulate on.

Take a deep breath in, open your mouth, and exhale. Now, cup your hands and place them over your closed eyes. Open your eyes into this darkness. Slowly begin to pull your hands down, allowing your eyes to adjust to the light of the day that warms up. Thank you for allowing me to walk you through this journey.

Appendix F

Equipment List

The following equipment charts include the majority of tools used by small- to mid-scale mushroom farms for indoor and outdoor cultivation projects.

Radical Mycology

	Frequency Used			Common Sources									Technique								
	Disposable	Reusable	Infrastructure	Online Auction	Hardware Store	Farm and Feed	Grocery Store	Pharmacy	Classifieds	Homemade	Other	Specialty	Agar Work	Liquid Culture	Grain Spawn	Sawdust Spawn	(Faux) Compost	Fruiting	Outdoor Work	Straw	Culture Storage	Medicine Making
10" Diameter (16" Flat) 3 Mil Plastic Tubing	●			●								●								●		
16 Ga Luer-Lok Syringe Needles		●		●		●		●				●		●	●	●						
(2x4) Wood Boards			●		●				●										●			
20 mL Scintillation Tubes		●		●																	●	
24-Hour Timer			●	●	●	●												●				
5-Gallon Buckets		●			●	●	●		●		●									●		
55-Gallon Food Grade Steel Drum			●	●		●			●		●					●						
A-Frame Or Bunyip			●							●									●			
Agar	●			●			●				●	●	●	●							●	
Alcohol Flame			●	●				●		●	●	●	●	●	●						●	
Alcohol Wipes	●						●	●						●	●	●						
Aluminum Foil	●						●						●	●	●	●	●				●	
Baby Food Jars		●					●						●								●	
Bacticinerator			●	●							●		●	●	●						●	
Bee's or Soy Wax	●			●		●	●				●	●							●			
Big Metal Spoon			●			●	●		●						●	●	●					●
Biochar	●					●				●						●	●		●	●		
Biochar Stove			●							●		●				●	●		●	●		
Blender			●	●			●		●		●			●	●	●			●			●
Board With Nails Or Arrowheads			●							●										●		
Bran	●						●									●						
Bulk Pasteurizer			●							●						●	●					
Burlap Coffee Sacs	●	●							●		●								●	●		
Canning Jars			●	●	●	●	●		●				●	●	●	●	●				●	●
Capsule Maker			●	●					●		●											●
Cardboard	●						●		●		●								●			
Chainsaw			●																●			
Coated Stir Bars			●	●							●	●		●								●
Coconut Coir	●			●		●											●					
Coffee grounds	●										●									●		
Colander			●				●		●						●							
Compost Tea Maker			●								●						●		●			
Compost Thermometer			●	●	●	●			●		●						●		●			
Cooking Trays			●				●				●						●					
Cotton Balls	●					●	●	●						●	●	●						
Crock Pot			●	●			●		●										●			●
Dehydrator			●	●		●	●		●	●								●				●
Digital Scale			●	●					●		●		●	●	●	●	●	●				●

Radical Mycology

	Frequency Used			Common Sources										Technique									
	Disposable	Reusable	Infrastructure	Online Auction	Hardware Store	Farm and Feed	Grocery Store	Pharmacy	Classifieds	Homemade	Other	Specialty	Agar Work	Liquid Culture	Grain Spawn	Sawdust Spawn	(Faux) Compost	Fruiting	Outdoor Work	Straw	Culture Storage	Medicine Making
Distillation Train			●	●								●										●
Distilled Water	●						●														●	
Dual Function Timer			●							●	●							●				
Electric Drill Or Angle Grinder			●		●				●										●	●		
Empty Capsules	●			●							●											●
Face Mask	●	●		●	●			●	●				●	●	●	●	●	●		●	●	
Flow Hood			●	●						●		●	●	●	●	●					●	
Fly Tape	●			●	●	●												●				
Garden Pots		●		●	●	●			●									●	●	●		
Garden Tools			●		●	●			●							●	●		●	●		
Glove Box			●	●					●	●			●	●	●	●					●	
Gnatrol	●			●		●					●							●				
Grains	●			●		●	●								●						●	
Gypsum	●				●	●							●	●	●	●	●		●			
Hair Net	●	●		●				●					●	●	●	●	●	●		●		
High Temp RTV Silicone	●			●	●	●								●	●	●					●	
Hydrated Lime	●				●	●										●	●		●	●		
Hydrogen Peroxide	●							●					●							●		
Hydrostat			●	●							●	●						●				
Impulse Sealer			●	●							●				●	●				●		
Incubator			●	●						●		●	●	●	●	●					●	
Indoor greenhouse			●	●					●	●		●						●				
Isopropyl Alcohol	●				●	●	●	●					●	●	●	●	●	●		●	●	
Large Pot			●	●	●	●	●		●					●	●	●	●					
Latex Gloves	●			●		●	●	●					●	●	●	●	●			●	●	
Latex Paint			●		●																	
Light Malt Extract	●			●							●	●	●	●							●	
Logs	●								●		●								●			
Magnetic Stir Plate			●	●					●	●				●								●
Manure	●								●		●						●					
Mircopore Tape	●			●	●		●	●					●	●	●	●					●	
Mixing Screen			●							●					●	●	●		●			
Multch Shredder Or Weed Wacker			●	●	●	●			●											●		
Nutritional Yeast	●						●						●	●							●	
Packaging Tape	●				●		●											●		●		
Paint Brushes			●		●						●								●			
Palm Inoculator			●	●								●							●			
Parafilm	●			●							●	●	●								●	
Peat Moss	●					●											●	●				

Radical Mycology

	Frequency Used			Common Sources										Technique									
	Disposable	Reusable	Infrastructure	Online Auction	Hardware Store	Farm and Feed	Grocery Store	Pharmacy	Classifieds	Homemade	Other	Specialty	Agar Work	Liquid Culture	Grain Spawn	Sawdust Spawn	(Faux) Compost	Fruiting	Outdoor Work	Straw	Culture Storage	Medicine Making
Peptone	●			●							●	●	●	●							●	
Perlite	●				●	●	●											●				
Petri Dishes	●	●		●							●	●	●								●	
pH & Moisture Meter			●	●	●	●					●	●				●	●		●			
Pillowcase Or Muslin Sacks			●							●	●					●				●		
Plastic Food Storage Wrap	●						●						●								●	
Plastic Tubs			●		●	●	●		●		●						●	●	●			
Polyethylene Bags	●			●							●					●	●					
Polyfil	●										●			●	●	●					●	
Polypropylene 15 mL Centrifuge Tubes	●			●							●										●	
Polypropylene Filter Patch Bags	●			●							●	●			●	●						
Pressure Cooker			●	●	●	●	●		●			●	●	●	●	●					●	
Propane Burner and Tank			●	●	●	●			●		●					●			●	●		
Pulsed Voltage Generator			●								●							●				
Sawdust	●								●		●					●			●			
Scalpels and Spatulas			●	●				●	●	●		●	●		●						●	
Scientific Hygrometer			●	●							●							●				
Scissors			●		●		●						●	●	●	●		●	●	●	●	
Space Heater			●		●								●	●	●	●	●	●				
Spray Bottles			●	●	●	●	●	●					●	●	●	●	●	●	●	●	●	
Stiff Wire	●	●			●										●	●			●		●	
Straw	●				●	●			●										●	●		
Substrate Tumbler			●						●	●	●					●	●		●			
Syringes	●	●		●		●		●	●					●	●	●					●	
Tarp			●		●				●							●	●		●			
Totes			●		●		●		●							●		●	●	●		
Trashcan			●		●		●		●										●	●		
Tyvek Sleeves	●	●		●				●				●	●	●	●	●	●					
Vermiculite	●				●	●	●										●					
Well or Spring Water	●										●		●	●	●	●	●		●	●	●	
Wire Basket			●							●										●		
Wood Chipper			●	●	●	●			●							●			●	●		
Wood Chips	●								●	●	●					●			●			
Ziploc Bags	●						●													●	●	

Appendix G

Cultivation Parameters

The following charts reflect the optimal incubation, pinning, and fruiting conditions for 32 of the most commonly cultivated mushroom species, as well as the preferred substrates of 108 commonly and uncommonly cultivated saprophytic mushroom species. These lists are not exhaustive—feel free to experiment with novel substrates. The initials of a species' Latin name are often used as a shorthand to label containers. They are also listed here for reference.

Radical Mycology

			Incubation Temp. – °F (°C)				Pinning Temperature – °F (°C)								Pinning Humidity (%)			
			65–70 (18–21)	70–75 (21–24)	75–80 (24–27)	80–85 (27–30)	40–45 (4–7)	45–50 (7–10)	50–55 (10–13)	55–60 (13–15)	60–65 (15–18)	65–70 (18–21)	70–75 (21–24)	75–80 (24–27)	80–85 (27–30)	80–85	85–90	90–95	95–100
AB	*Agaricus bisporus*	Button		•	•						•							•	•
ABr	*Agaricus blazei*	Almond Port		•	•								•			•	•		
AA	*Agrocybe aegerita*	Pioppino		•	•				•	•								•	•
AuP	*Auricula polytricha*	Cloud Ear			•	•				•	•	•						•	•
CN	*Clitocybe nuda*	Blewit		•						•	•							•	•
CC	*Coprinus comatus*	Shaggy Mane		•	•						•	•						•	•
FV	*Flamulina velutipes*	Enokitake		•			•	•										•	•
GL	*Ganoderma lucidum*	Reishi		•	•							•	•					•	•
GF	*Grifola frondosa*	Maitake		•					•	•								•	•
HE	*Hericium erinaceus*	Lion's Mane		•					•	•								•	•
HC	*Hypholoma capnoides*	Conifer Tuft		•				•	•									•	•
HS	*Hypholoma sublateritium*	Brick Cap		•					•	•								•	•
HT	*Hypsizygus tessulatus*	Buna Shimeji		•					•	•								•	•
HU	*Hypsizygus ulmarius*	Elm Oyster		•	•				•									•	•
LE	*Lentinula edodes*	Shiitake		•	•				•	•								•	•
MA	*Morchella angusticeps*	Black Morel		•			•											•	•
PnC	*Panaeolus cyanescens*	Pan Cyans				•								•				•	•
PN	*Pholiota nameko*	Nameko			•	•			•	•								•	•
PC	*Pleurotus citrinopileatus*	Yellow Oyster			•	•							•	•				•	•
PlC	*Pleurotus cystidiosus*	Abalone			•	•							•	•				•	•
PD	*Pleurotus djamor*	Pink Oyster			•							•	•					•	•
PE	*Pleurotus eryngii*	King Oyster							•	•								•	•
PO	*Pleurotus ostreatus*	Pearl Oyster		•					•	•	•							•	•
PP	*Pleurotus pulmonarius*	Pheonix Oyster			•	•			•	•	•	•	•					•	•
PTR	*Pleurotus tuber-regium*	Tiger King				•								•	•			•	•
PU	*Polyporus umbellatus*	Umbrella Polypore	•	•			•	•	•	•								•	•
PCu	*Psilocybe cubensis*	Cubes		•	•	•							•	•					•
PCy	*Psilocybe cyanescens*	Wavy Caps	•	•				•	•									•	•
SCr	*Sparassis crispa*	Cauliflower		•					•	•								•	•
SRA	*Stropharia rugosoannulata*	King Stropharia		•	•				•	•							•	•	•
TV	*Trametes versicolor*	Turkey Tail			•	•			•	•	•	•	•					•	•
VV	*Volvariella volvacea*	Paddy Straw			•	•									•			•	•

Pinning CO_2 Concentration (ppm)							Fruiting Temperature – °F (°C)								Fruiting Relative Humidity (%)							Fruiting CO_2 Concentration (ppm)						
<500	500–750	750–1000	1000–1500	1500–2000	2000–3000	3000–4000	45–50 (7–10)	50–55 (10–13)	55–60 (13–15)	60–65 (15–18)	65–70 (18–21)	70–75 (21–24)	75–80 (24–27)	80–85 (27–30)	75–80	70–75	75–80	80–85	85–90	90–95	95–100	<500	500–750	750–1000	1000–1500	1500–2000	2000–3000	3000–4000
	•									•									•			•	•	•				
	•												•		•			•				•	•	•	•	•		
•	•	•	•	•					•	•										•		•	•	•	•	•		
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			•	•	•	•								•					•	•					•	•	•	•

Radical Mycology

			Commonly Cultivated	Fruiting Substrates					Outdoor			Wood Types				
				Nut. Saw	Past. Saw	Faux/Comp.	Straw	Ag Waste	Logs/Stumps	Bed or Row	Raft Style	Alder	Ash	Aspen	Beech	Birch
AAu	*Agaricus augustus*	Prince				•				•						
AB	*Agaricus bisporus*	Button	•			•				•						
ABr	*Agaricus brasiliensis/blazei*	Almond Portobello	•			•				•						
AS	*Agaricus subrufrescens*	Almond Agaricus				•				•						
AA	*Agrocybe aegerita*	Pioppino	•	•	•		•			•						
AM	*Agrocybe molesta*	Molesta		•					•	•						
AP	*Agrocybe praecox*	Spring Agrocybe		•					•							
ArM	*Armillaria spp.*	Honey Mushroom		•	•			•	•							
AuP	*Auricula polytricha*	Cloud Ear	•	•	•				•							
AuA	*Auricularia auricula-judae*	Wood Ear	•	•	•			•	•							
CI	*Calocybe indica*	Milky Mushroom				•	•	•								
CG	*Calvatia gigantea*	Giant Puffball				•										
CU	*Cerrena unicolor*	Mossy Maze Polypore		•					•						•	
CB	*Chlorophyllum brunneum*	Shaggy Parasol				•				•						
CO	*Chlorophyllum olivieri*	Shaggy Parasol				•				•						
CR	*Chlorophyllum rachodes*	Shaggy Parasol				•				•						
CN	*Clitocybe nuda*	Blewit				•	•			•						
CC	*Coprinus comatus*	Shaggy Mane				•				•						
FH	*Fistulina hepatica*	Beefsteak Fungus		•					•							
FV	*Flamulina velutipes*	Enokitake	•	•	•			•	•			•		•		
FF	*Fomes fomentarius*	Tinder Conk		•					•			•		•	•	•
FO	*Fomitopsis officinalis*	Agarikon		•												
FP	*Fomitopsis pinicola*	Red Belted Conk		•					•							•
GA	*Ganoderma applanatum*	Artist's Conk		•					•			•				
GC	*Ganoderma curtisii*	Golden Reishi		•					•							
GL	*Ganoderma lucidum*	Reishi	•	•	•			•	•		•	•				
GO	*Ganoderma oregonense*	Oregon Reishi		•					•							
GS	*Ganoderma sinensis*	Black Reishi		•					•							
GT	*Ganoderma tsuage*	Hemlock Reishi		•					•							
GF	*Grifola frondosa*	Maitake	•	•					•			•			•	
GS	*Gymnopilus spectabilis*	Big Laughing Gym		•					•	•		•				
HAb	*Hericium abietes*	Comb Tooth	•	•					•							
HAm	*Hericium americanum*	Coral Tooth	•	•					•						•	
HE	*Hericium erinaceus*	Lion's Mane	•	•					•			•			•	
HC	*Hypholoma capnoides*	Conifer Tuft		•	•		•		•	•	•					
HF	*Hypholoma fasciculare*	Sulfur Tuft		•	•				•							

Wood Types
Box Elder
Chestnut
Conifer
Cottonwood
Cypress
Douglas-Fir
Elder
Elm
Eucalyptus
Fir
Hemlock
Hickory
Honey Locust
Hornbeam
Juniper
Larch
Madrone
Maple
Oak
Pine
Plum
Poplar
Redwood
Spruce
Sweetgum
Tanoak
Walnut
Willow

Radical Mycology

			Commonly Cultivated	Fruiting Substrates					Outdoor			Wood Types				
				Nut. Saw	Past. Saw	Faux/Comp.	Straw	Ag Waste	Logs/Stumps	Bed or Row	Raft Style	Alder	Ash	Aspen	Beech	Birch
HS	*Hypholoma sublateritium*	Brick Cap	•	•	•		•		•		•	•				
HM	*Hypsizygus marmoreus*	White Buna Shimeji	•	•												
HT	*Hypsizygus tessulatus*	Brown Buna Shimeji	•	•					•			•			•	
HU	*Hypsizygus ulmarius*	Elm Oyster	•	•	•		•	•	•	•		•			•	
IO	*Inonotus obliquus*	Chaga		•					•			•			•	•
IL	*Irpex lacteus*	White Toothed Polypore		•					•							
KM	*Kuehneromyces mutabilis*	Changeable Pholiota		•					•							
LC	*Laetiporus conifericola*	Chicken of the Woods		•					•							
LG	*Laetiporus gilbertsonii*	Chicken of the Woods		•					•							
LS	*Laetiporus sulphureus*	Chicken of the Woods		•					•							
LE	*Lentinula edodes*	Shiitake	•	•			•	•	•			•	•		•	•
LG	*Lentinus giganteus*	Uru Paha	•	•												
LL	*Lentinus lepideus*	Train Wrecker		•					•							
LT	*Lentinus tigrinus*	Little Shiitake	•	•												
LB	*Lenzites betulina*	Gilled Polypore		•					•							
LR	*Lignosus rhinocerotis*	Tiger Milk						•								
MT	*Macrocybe titans*	Big Mama						•								
MP	*Macrolepiota procera*	Parasol				•										
MA	*Morchella angusticeps*	Black Morel		•												
MC	*Mutinus caninus*	Dog Stinkhorn				•										
OJ	*Omphalotus japonicus*	Tsukiyotake		•					•							
OO	*Omphalotus olearius*	Jack-O'-Lantern		•					•							
PnC	*Panaeolus cyanescens*	Pan Cyans	•			•										
PS	*Panellus stipticus*	Luminescent Panellus		•	•				•	•		•	•		•	•
PIm	*Phallus impudicus*	Stinkhorn				•		•	•			•				
PI	*Phallus indusiata*	Bamboo Fungus	•			•		•								
PB	*Phellinus baumii*	Phellinus Fungus		•					•			•				•
PIg	*Phellinus igniarius*	Iqmik		•					•			•		•		•
PL	*Phellinus linteus*	Black Hoof Fungus		•					•							
PhA	*Pholiota adiposa*	Adiposa		•												
PN	*Pholiota nameko*	Nameko	•	•	•				•	•	•	•		•	•	•
PBe	*Piptoporus betulinus*	Birch Polypore		•					•						•	•
PC	*Pleurotus citrinopileatus*	Yellow Oyster	•	•											•	
PCo	*Pleurotus cornucopiae*	Branched Oyster	•	•												
PlC	*Pleurotus cystidiosus*	Abalone	•	•												
PD	*Pleurotus djamor*	Pink Oyster	•	•	•		•		•							

Wood Types
Box Elder
Chestnut
Conifer
Cottonwood
Cypress
Douglas-Fir
Elder
Elm
Eucalyptus
Fir
Hemlock
Hickory
Honey Locust
Hornbeam
Juniper
Larch
Madrone
Maple
Oak
Pine
Plum
Poplar
Redwood
Spruce
Sweetgum
Tanoak
Walnut
Willow

Radical Mycology

			Commonly Cultivated	Fruiting Substrates					Outdoor			Wood Types				
				Nut. Saw	Past. Saw	Faux/Comp.	Straw	Ag Waste	Logs/Stumps	Bed or Row	Raft Style	Alder	Ash	Aspen	Beech	Birch
PE	*Pleurotus eryngii*	King Oyster	•	•	•		•			•		•				
PF	*Pleurotus ferulae*	White Elf Mushroom	•	•												
PNe	*Pleurotus nebrodensis*	Bailing Mushroom	•	•												
PO	*Pleurotus ostreatus*	Pearl Oyster	•	•	•		•		•	•		•		•	•	•
PPo	*Pleurotus populinus*	Aspen Oyster	•	•												
PP	*Pleurotus pulmonarius*	Pheonix Oyster	•	•	•		•		•			•	•	•	•	•
PSC	*Pleurotus sajor-caju*	Dhingri Oyster				•										
PSa	*Pleurotus salmoneostramineus*	Flamingo				•										
PTR	*Pleurotus tuber-regium*	Tiger King Mushroom				•										
PoP	*Podaxis pistillaris*	Desert Puffball				•										
PSq	*Polyporus squamosus*	Dryad's Saddle		•					•							
PU	*Polyporus umbellatus*	Umbrella Polypore		•					•				•		•	•
PA	*Psilocybe azurescens*	Azies		•	•					•		•				
PCu	*Psilocybe cubensis*	Cubes	•			•	•			•						
PCy	*Psilocybe cyanescens*	Wavy Caps		•	•					•		•			•	•
PM	*Psilocybe mexicana*	Philosopher's Stone	•			•										
SC	*Schizophyllum commune*	Split Gill		•					•			•		•		•
SCr	*Sparassis crispa & S. radicata*	Cauliflower		•					•							
SH	*Stereum hirsutum*	Hairy Parchment		•					•							
SM	*Stropharia melanosperma*	Round Head				•										
SRA	*Stropharia rugosoannulata*	King Stropharia	•	•	•		•	•		•						
Tsp	*Termitomyces spp.*	Termite Mushroom				•										
TG	*Trametes gibbosa*	Lumpy Bracket		•					•							
THi	*Trametes hirsuta*	Hairy Bracket		•					•							
TO	*Trametes ochracea*	White Rot Fungus		•					•							
TP	*Trametes pubescens*	White Rot Fungus		•					•							
TV	*Trametes versicolor*	Turkey Tail	•	•	•				•			•	•	•	•	•
TF	*Tremella fuciformis*	Snow Fungus	•	•												
TM	*Tremella mesenterica*	Witch's Butter	•	•												
TH	*Tremiscus helvelloides*	Apricot Jelly Fungus		•												
TC	*Tricholoma crassum*	Rhino Feet Mushroom				•										
VV	*Volvariella volvacea*	Paddy Straw	•				•	•								
WE	*Wolfiporia extensa*	Tuckahoe		•					•							
XH	*Xylaria hypoxylon*	Carbon Antlers	•	•												
XN	*Xylaria nigripes*	Wu Ling Shen	•	•												
XP	*Xylaria polymorpha*	Dead Man's Fingers	•	•											•	

Wood Types
Box Elder
Chestnut
Conifer
Cottonwood
Cypress
Douglas-Fir
Elder
Elm
Eucalyptus
Fir
Hemlock
Hickory
Honey Locust
Hornbeam
Juniper
Larch
Madrone
Maple
Oak
Pine
Plum
Poplar
Redwood
Spruce
Sweetgum
Tanoak
Walnut
Willow

Media Cookbook

Cup	Ounce	Tbsp.	tsp.	mL
1	8	16	48	237
3/4	6	12	36	177
2/3	5	11	32	158
1/2	4	8	24	118
1/3	3	5	16	79
1/4	2	4	12	59
1/8	1	2	6	30
1/16	0.5	1	3	15

Agar Media Recipes

Unless noted, all agar recipes start with 500 milliliters of water and 10 grams of agar. Never use the following antifungal ingredients in media recipes: coconut, garlic, pomegranate, cinnamon, cloves, curry, and cilantro.

Commonly Used Media

Malt Extract Agar (ME)
- Dry, light malt (barley) extract – 10 g

Malt Yeast Extract (MYA)
- Malt – 10 mL
- Yeast – 1 mL

Malt Extract with Activated Carbon (MEAC)
- Malt – 10 g
- Activated carbon – 1 g

Malt Extract with Peptone (MEP)
- Malt – 10 g
- Peptone – 1 g

Malt Extract with Yeast and Peptone (MYAP)
- Malt – 10 g
- Yeast – 1 g
- Peptone – 1 g

Malt Extract with Yeast, Peptone, and Activated Carbon (MEPYAC)
- Malt – 10 g
- Peptone – 1 g
- Yeast – 1 g
- Activated carbon – 1 g

Malt Extract with Milo (MEM)
- Malt – 10 g
- Ground milo – 10 g

Malt Extract with Corn (MEC)

- Malt – 10 g
- Ground corn – 10 g

Malt Extract with Honey (MEH)

- Malt – 10 g
- Honey – 16 g

ATTC Medium 597

- Malt - 3.75 g
- Yeast – 0.3 g
- Peptone – 0.5 g

MYAP with Multi-vitamin (MYMP)

- Fresh ground crickets – 8 g
- Multi vitamin – 0.01 g
- Peptone – 1 g
- Yeast – 1 g
- Malt – 10 g

Add multi-vitamin after sterilization

MYAP with elements (MYPMCZ)

- Yeast – 1 g
- Peptone – 1 g
- Calcium – 0.01 g
- Magnesium – 0.01 g
- Zinc – 0.01 g

MYA with Cordyceps sinensis *(CS4MY)*

- Malt - 3.75 g
- Yeast – 0.3 g
- Ground *Cordyceps sinensis* 4 – 10 g

Potato Dextrose Agar (PDA)

- Diced and boiled potatoes – 150 g
  OR Potato starch – 10 g
- Dextrose – 7 g

In 500 mL of water, boil 150 g of potatoes. Strain out the solids, bring the solution back to 500 mL with water, then add remaining ingredients. Five grams of potato flakes can be used as a substitute.

Potato Dextrose Agar (PDA)

- Dextrose or Honey/Corn syrup – 7 g or 10 mL
- Diced potatoes – 150 g

Potato Dextrose Yeast Agar (PDYA)

- Dextrose or Honey/Corn syrup – 7 g or 10 mL
- Diced potatoes – 150 g
- Yeast – 1 g

Potato, Ammonium citrate, Thiamin Agar (PAT)

Cordyceps militaris is known to fruit from this media when used to inoculate brown rice.

- Potato broth – 100 mL
- KH_2PO_4 – 1 g
- $MgSO_4$ – 0.5 g
- Peptone – 1.5 g
- Ammonium citrate – 0.5 g
- Dextrose – 15 g
- Thiamine (B1 vitamin) – 0.025 g

Potato Skin Dextrose Agar (PSDA)

- Dried potato skins – 10 g
- Dextrose – 7 g

Barley Flour Malt Extract Agar (BFMA)

- Barley flour – 40 g
- Malt extract – 2 g
- Yeast extract (optional) – 1 g

Oatmeal Agar (OA)

- Filtered, cooked oatmeal – 30 g

Cornmeal Malt Agar (CMMA)

- Cornmeal – 10 g
- Dextrose – 7 g

Dog Food Agar (DFA)

- Dried, ground dog food – 10 g
- Amaranth flour – 10 g
- Dextrose or malt extract – 2 g

Amaranth Soy Agar (ASA)

- Amaranth flour – 20 g
- Soy flour – 20 g

EntheoGenesis Agar (EA)

- Amaranth flour – 20 g
- Soy flour – 20 g
- Brown rice flour – 10 g
- Potato flour – 10 g
- Malted barley – 2 g

Moonflower's Rice Malt-Alfalfa-Brewer's Yeast Agar (MRMABYA)

Soak 1 cup of alfalfa and 2 cups of rice in 1.5 quarts of clean water for 2 hours at room temp. Stir occasionally. Filter out solids. Pour a packet of baker's yeast in water. After 30 minutes, filter out the solids. Combine liquids and add 1 tablet of crushed dolomite. Supports luxuriant mycelial growth and germinates spores.

Spore Germination Agar #1
- Cornmeal – 10 g
- Dextrose – 1 g
- Yeast – 0.5 g

Spore Germination Agar #2
- Cornmeal – 10 g
- Dextrose – 3.5 g
- Sucrose – 5 g
- Yeast – 0.5 g
- KH_2PO_4 – 0.5 g

Spore Germination Agar #3
- Cornmeal – 10 g
- Malt – 0.8 g

Spore Germination Agar #4
- Cornmeal – 10 g
- Glucose – 1 g
- Sucrose – 1.5 g
- Yeast – 0.5 g

Juice / Broth Media

V8 Juice Agar (V8A)
- $CaCO_3$ – 1.5 g
- V8 Juice – 100 mL

Beef Broth Agar (BBA)
- Beef broth – 20 mL
- Malt – 5 g
- Yeast – 1 g

Chicken Broth Agar (CBA)
- Chicken broth – 20 mL
- Malt – 5 g
- Yeast – 1 g

Butternut Squash Soup Agar (BNSA)
- Butternut squash soup – 20 mL
- Malt – 5 g
- Yeast – 1 g

Beef Yeast Agar (BYA)
- H_2O – 300 mL
- Yeast – 2 g
- Beef broth – 200 mL

Malt with Activated Carbon and KOH (R7)
- Epsom salts – 0.25 g
- Activated carbon – 1.3 g
- Malt – 12.5 g
- Humus – 2.5 g
- KOH 1% – 20 mL

Chemical Media

Organic Medium Agar (OMA)
- Glucose – 5 g
- Peptone – 0.5 g
- Yeast – 0.05 g
- KH_2PO_4 – 1 g
- $MgSO_4 \cdot 7H_2O$ 0.15 g
  OR $MgSO_4$ – 0.075 g

Czapek's Medium
- $NaNO_3$ – 1.5 g
- K_2HPO_4 – 0.5 g
- $MgSO_4$ – 0.25 g
- KCl – 0.25 g
- $FeSO_4$ – 0.0187 g
  OR $Fe\ SO_4 \cdot 7H_2O$ – 0.0094 g
- Dextrose – 15 g

Used for the isolation and culture of saprobic soil microorganisms.

Animal Related Media

Blood Worm Agar (BW)
- Blood worms – 5 g

Krill Agar (KA)
- Krill – 10 g

Fish Flake Dextrose Agar (FDA)
- Fish flakes – 3 g
- Dextrose – 10 g

Meal Worm Agar (MWA)
- Meal worms (ground) – 10 g
- Dextrose – 3 g
- Yeast – 1 g

Fishy Wax Agar (FWA)
- Bee's wax – 1 g
- Krill, tubiflex worms, and fish flakes – 3.3 g each

Manure Agar

- Ground horse manure – 50–60 g

Boil manure in water for 10 minutes, let sit for 16–20 hours, filter out solids, bring back to 500 mL and add agar.

Compost Agar

Air-dry and then grind hot compost obtained during its peak state. Mix 50 g of this dried compost powder to 750 mL of water. PC for 1 hour at 15 psi. Filter twice through cheese cloth. Bring volume up to 500 mL. Add 10 g agar and PC as normal.

Complete Media (CM)

- Sucrose – 15 g
- Ammonium tartrate (NH_4^-) – 2.5 g
- Ammonium nitrate (NH_4NO_3) – 0.5 g
- Magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$) – 0.25 g
- Sodium chloride (NaCl) – 0.5 g
- Calcium chloride ($CaCl_2$) – 0.065 g
- Yeast – 0.5 g
- Monopotassium phosphate (KH_2PO_4) – 0.5 g

Richard's Medium (for T. harzianum*)*

- Potassium nitrate – 5 g
- Monopotassium dihydrogen phosphate – 2.5 g
- Magnesium sulphate – 1.25 g
- Ferric chloride – 0.01 g
- Sucrose – 25 g

wMY Agar *(For Protostelid slime molds)*

- Malt extract – 0.01 g
- Yeast extract – 0.01 g
- Dibasic potassium phosphate – 0.375 g

Distilled Water Agar (DWA)

This formula should be made solely with distilled water and agar.

Sea Water Agar (SWA)

- H_2O – 125 mL
- Agar – 10 g
- Sea water – 375 mL
- Beef extract – 5 g
- Peptone – 5 g

Dissolve the beef extract and peptone in warmed H_2O. Adjust the pH to 7.8 and boil for 10 minutes. Readjust pH to 7.3 and add agar.

Honey Agar (HON)

- Honey – 16 g

Beet Root Agar (BRA)

- Beet root supplement – 3 g
- Malt – 10 g

Peaches Malt Agar (PMA)

- Canned peaches mash – 10 g
- Dextrose – 7 g

Spirulina Agar (SPA)

- Spirulina supplement – 3 g
- Malt – 10 g

Nori Agar (NorA)

- Nori – 3 g
- Malt – 10 g

Brine Agar (BA)

- Brine – 10 g

Bean Soup Agar (BSA)

- H_2O – 400 mL
- Agar – 10 g
- Bean soup – 100 mL

Carrot Malt Agar (CMA)

- Carrot mash – 20 g
- Malt – 5 g

Sunflower Seed Agar (SFS)

- Ground sunflower seeds – 10 g

Almond Agar (AA)

- Ground almonds – 10 g

Ectomycorrhizal Media

Modified Melin-Norkrans Agar (MMN) *– pH 5.8*

- $(NH_4)_2HPO_4$ – 1.25 g
- KH_2PO_4 – 2.5 g
- $MgSO_47H_2O$ – 0.75 g
- $CaCl_22H_20$ – 0.25 g
- NaCl – 0.125 g
- Fe EDTA – 0.1 g
- Glucose – 5 g
- Malt extract – 1.5 g
- Thiamine HCl – 0.05 g

FDA Agar *– pH 5.0*

- NH_4Cl – 2.5 g
- KH_2PO_4 – 2.5 g
- $MgSO_47H_2O$ – 2.5 g
- Glucose – 10 g
- Malt extract – 2.5 g

PACH Agar *– pH 5.4*

- $C_4H_{12}N_2O_6$ – 2.5 g
- KH_2PO_4 – 5 g
- $MgSO_47H_2O$ – 2.5 g
- $CaCl_22H_20$ – 0.25 g
- Fe EDTA – 0.1 g
- H_3BO_3 – 0.014 g
- $MnCl_22H_20$ – 0.015 g
- $ZnSO_47H_20$ – 0.00315 g
- $Na_2Mo_42H_20$ – 0.00125 g
- Maltose – 2.5 g
- Glucose – 10 g
- Thiamine HCl – 0.05 g

Lichen Media

Lilly and Barnett's Medium Agar

- Glucose – 5 g
- Asparagine – 1 g
- KH_2PO_4 – 0.5 g
- $MgSO_4 \cdot 7H_2O$ – 0.25 g
- $Fe(NO_3) \cdot 9H_2O$ – 0.1 mg
- $MnSO_4 \cdot 4H_2O$ – 0.05 mg
- Thiamine – 0.05 mg
- Biotin – 2.5 um
- Distilled water – 500 mL

BBM Bold's Basal Medium
(Chlorobiont Medium)

- $NaNO_3$ – 250 mg
- KH_2PO_4 – 175 mg
- K_2HPO_4 – 75 mg
- $MgSO_4 \cdot 7H_2O$ – 75 mg
- $CaCl_3 \cdot 2H_2O$ – 25 mg
- NaCl – 25 mg
- EDTA – 50 mg
- KOH – 31 mg
- $FeSO_4 \cdot 7H_2O$ – 4.98 mg
- H_3BO_3 – 11.42 mg
- $ZnSO_4 \cdot 7H_2O$ – 8.82 mg
- $MnCl_2 \cdot 7H_2O$ – 1.44 mg
- MoO_3 – 0.71 mg
- $CuSO_4 \cdot 5H_2O$ – 1.57 mg
- $Co(NO_3)_2 \cdot 6H_2O$ – 0.49 mg

Make up to 1 L with distilled water. For a solid medium, add 15–20 g agar.

MDM *(Cyanobiont medium) – pH 8.0*

- KNO_3 – 100 mg
- $MgSO_4 \cdot 7H2O$ – 25 mg
- K_2HPO_4 – 25 mg
- NaCl – 10 mg
- $CaCl_2 \cdot 2H_2O$ – 1 mg
- Fe solution[a] – 0.1 mL
- A_5 solution[b] – 0.1 mL
- Agar – 1.5 g
- Distilled water – 99.8 mL

a) Fe solution

- $FeSO_4 \cdot 7H_2O$ – 200 mg
- Distilled water – 100 mL
- Conc $\cdot H_2SO_4$ – 0.026 mL (i.e. 2 drops/500 mL)

b) A_5 solution

- H_3BO_3 – 286 mg
- $MnSO_4 \cdot 7H2O$ – 250 mg
- $ZnSO_4 \cdot 7H2O$ – 22.2 mg
- $CuSO_4 \cdot 5H2O$ – 7.9 mg
- $Na_2MoO_4 \cdot 2H2O$ – 2.1 mg
- Distilled Water – 100 mL

Toxins are created if the agar is autoclaved with the mineral solution. To avoid, autoclave the mineral mixture and agar separately, using only half the total amount of distilled water in each. Mix the two together after they have cooled to 122°F (50°C) and pour into plates.

Liquid Media Recipes

All recipes are for 500 mL of water (approximately 2 cups). I often add a pinch of gypsum to every jar as well.

Complete LC (CLC)

- Malt – 10 g
- Peptone – 1 g
- Yeast – 0.3 g
- Vegetable oil – 5 drops
- Ground grain – 1 g

Malt Extract Dextrose LC (MDLC)

- Dextrose – 1 Tbsp.
- Light malt extract – 1 Tbsp.

Honey LC (HLC)

- Honey – 2 tsp. or 10 g

Corn Syrup LC (CSLC)

- Corn Syrup – 2 tsp or 10 g

Lysogeny LC (LLC)

- Dextrose – 10 g
- Peptone – 5 g
- Yeast – 2.5 g

Common Substrate Ingredients

If properly prepared and used in the correct proportions, the following ingredients can be added to substrate formulas. Be sure that their incorporation into a formula reflects the niche of the fungus you are working with. But feel free to play around, you never know what you might discover.

Gypsum (Calcium sulfate [CaSO])

Provides sulfur that helps increase yield, speed, and mycelial health. Added at 2–10% by dry substrate weight.

Worm Castings

Adds nitrogen, phosphorus, potash, and other nutrients. Added at 10–15% by volume.

Chicken manure

A rich nitrogen source. Use small amounts (around 1% by volume).

Paper Products

Many fungi can be grown on a wide variety of paper products. These substrates are typically low in nutrients and require supplementation. They may also contain undesirable inks, dyes, heavy metals, etc. Consume mushrooms grown on paper waste with caution.

Coffee

Adds nitrogen. Use weak coffee or spent coffee grounds; fresh grounds are too acidic.

Spent Malt

Distillery and brewery waste can be used as substrates. Brewery grains are often acidic and need to have their pH raised. The addition of dry vermiculite or newspaper may be an easy way to offset excess moisture levels. Lightly roasted grains are preferred for their sugar profile.

Vermiculite or Conocut Coir

Adds texture and enhances moisture retention and aeration.

Agricultural "Waste"

Hundreds of byproducts from food and feed industries have been shown to be viable substrate options. These include:

- Agave
- Bamboo shoots/leaves/twigs
- Banana plants
- Coffee plants/husks
- Corncobs/stalks
- Cotton/textile/hemp waste
- Grape pomace
- Grasses, tea leaves
- Hair
- Kudzu
- Lavendar straw
- Lemongrass leaves
- Most seed and legume shells/pods/husks
- Nettle stalks
- Potato leaves
- Reeds
- Saguaro cactus
- Scotch broom
- Soybean roughage
- Sugar cane bagasse
- Sunflower plants
- Tobacco stems
- Water hyacinth
- Yucca

Substrate formulation is required when working with these alternative substrates. A quick search through journal databases can easily provide studies that utilized these and many other substrates for mushroom cultivation. Inoculation and fruiting processes are identical to the more commonly used substrates detailed in Chapter 8.

The following experimental additives are only used if monitoring pH and nitrogen levels:

Thiamin
One tablespoon per gallon of water. Adding too much B_1 can throw off nitrogen levels.

Humic/Fulvic acid
Aids mushrooms digestion and stimulates growth. Use 1 tablespoon per gallon of water.

Kelp
One-half to one teaspoon per gallon of pasteurization water. Adding too much will promote molds.

Seaweed extract/seaweed
Use up to 10% (by volume).

Pollen (not bee pollen)
Aids liquid inoculum growth.

Soybean/Sesame Meal
A long-term protein source and antioxidant with some anti-mold properties. Use at 2–4% of dry substrate weight.

Soybean/ Sesame Oil
Adds calcium, antioxidants, fats, and is possibly anti-mold. Only add small amounts (around 1 tablespoon per gallon of substrate).

Vegetable/Canola Oil
Contain lipids and nutrients for mycelial growth. Use 1–2 teaspoons per gallon of substrate.

Alkalinizing Agents

Alkalizing agents all have different chemical properties and applications. Most are caustic and a skin and eye irritant; caution is advised. Carefully read and follow all manufacturer directions.

Wood Ash
Just as it sounds. A cheap way to increase pH. Avoid questionable impurities from glossy papers, paint, adhesives, etc.

Horticultural/Hydrated/Slaked lime ($Ca[OH]_2$)
Produced by adding water to CaO. Causes rapid pH shifts, but is not long-lasting. When heated above 1077°F (580°C) it dehydrates, forming the oxide. Reacts with carbon dioxide to form calcium carbonate.

Pickling lime
A food grade form of calcium hydroxide with no additives or preservatives

Calcium carbonate ($CaCO_3$)
Helps buffer pH for an extended time. It comes in the following six forms:

Chalk
Soft in texture, chalk holds water well. Using a variety of piece sizes—from 1-inch thick to dust—helps improve casing structure and provides the longest lasting buffering action.

Marl
Dredged from dry lake bottoms, marl is a soft lime similar to chalk but has the consistency of clay. It is a composite of clay and calcium carbonate with good water holding capacity.

Oyster Shell
Mainly calcium carbonate along with other minor ingredients. Ground oyster shell is similar to limestone grit in its buffering action and its structural contributions to casings. Oyster shell should not be used as the sole buffering agent because of its low solubility in water.

Limestone
A sediment mineral composed mainly of calcium carbonate. It is similar to oyster shells.

Ground Limestone
Generally, ground limestone is weaker than hydrated lime, needing about 30% more to raise the pH by the same amount. Being cheap, it is the most widely used buffering agent for US *Agaricus* growers.

Limestone Grit
Produced in a fashion similar to ground limestone, limestone grit is rated according to particle size after being screened through varying meshes. Limestone grit is an excellent structural additive but has low buffering abilities. A number 9 grit is recommended.

Ectomycorrhizal (ECM) Plants (5% of Plants)

The primary ectomycorrhizal plant families are the Pinaceae, Fagaceae, Betulaceae, Salicaceae, and Dipterocarpaceae. Some species in the Cupressaceae and most species in the Myrtaceae and Caesalpinoideae also form ECM. Some plant groups that benefit from ectomycorrhizal fungi include:

- Alder (endo/ecto)
- Arborvitae
- Arctostaphylos
- Aspen (endo/ecto)
- Basswood
- Beech
- Birch
- Chestnut
- Chinquapin
- Cottonwood (endo/ecto)
- Douglas-Fir
- Eucalyptus
- Filbert
- Fir
- Hazelnut
- Hickory
- Hemlock
- Larch
- Linden
- Madrone
- Manzanita
- Oak
- Pecan
- Pine
- Poplar
- Spruce
- Willow (endo/ecto)

Non-Mycorrhizal Plants (5% of Plants)

The following plants or plant groups do not respond to endo or ectomycorrhizal fungi:

Brassicaceae

- Broccoli
- Brussels
- Cabbage
- Cauliflower
- Collards
- Kale
- Rutabaga

Others

- Beet
- Carnation
- Mustard
- Orchids
- Protea
- Rush
- Sedge
- Spinach

Arbuscular (Endo)Mycorrhizal Plants (80–90% of plant species)

The majority of wild plants, including shrubs, wildflowers, and broad leaf trees, associate with AMF, as do redwood, cedar, and juniper trees. These include:

- Almost all groups of Pteridophyta.
- Most groups of Gymnospermae.
- The majority of families in the Angiospermae.
- All palms.
- All plants in the Bryophyta.
- Almost all bulb plants.
- Anything related to roses, apples, peaches, pears, strawberries, etc.
- Most tropical plants (apart from orchids).
- The majority of horticultural species.
- Almost all crop plants.
- All cultivated grasses (but not all weedy grasses).
- Shrubs and foliage plants except for Rhododendron, Azalea, and Heath.
- Berries except for blueberries, cranberries, and lingonberries.
- Nut trees except pecan, hazelnuts, and filberts.
- Fruit trees including tropical fruits.
- Many wetland/aquatic species except rushes and horsetails.

It is easier to list the plant species that do not form AM than all of those that do. Common crops that form AM include:

- Acacia
- Agapanthus
- Alder (endo/ecto
- Alfalfa
- Almond
- Apple
- Apricot
- Artichoke
- Ash
- Asparagus
- Aspen (endo/ecto
- Avocado
- Bamboo
- Banana
- Barley
- Basil
- Bayberry
- Beans, all
- Beech
- Begonia
- Black cherry
- Blackberry
- Black locust
- Blue gramma
- Box Elder
- Boxwood
- Buckeye
- Bulbs, all
- Cacao
- Cactus
- Camellia
- Carrisa
- Carrot
- Cassava
- Ceanothus
- Cedar
- Celery
- Cherry
- Chrysanthemum
- Citrus, all
- Clover
- Coconut
- Coffee
- Coral Tree
- Corn
- Cotton
- Cottonwood (endo/ecto
- Cowpea
- Crab tree
- Creosote
- Cryptomeria
- Cucumber
- Currant
- Cypress
- Dogwood
- Eggplant
- Elm
- Eucalyptus
- Euonymus
- Fern
- Fescue
- Fig
- Flax
- Forsythia
- Fuchsia
- Gardenia
- Garlic
- Geranium
- Grapes, all
- Grasses, perennials
- Green Ash
- Guayule
- Gum
- Hackberry
- Hawthorn
- Hemp
- Herbs, all
- Hibiscus
- Holly
- Hostas
- Impatiens
- Jatropha
- Jojoba
- Juniper
- Kiwi
- Leek
- Lettuce
- Ligustrum
- Lily
- Locust
- Lychee
- Mahogany
- Magnolia
- Mahonia
- Mango
- Maples, all
- Marigolds
- Mesquite
- Millet
- Mimosa
- Morning glory
- Mulberry
- Myrtle
- Nasturtium
- Okra
- Olive
- Onion
- Pacific yew
- Palms, all
- Pampas grass
- Passion fruit
- Papaya
- Paw paw
- Peas
- Peach
- Peanut
- Pear
- Peppers, all
- Pistachio
- Persimmon
- Pittosporum
- Plum
- Podocarpus
- Poinsettia
- Poplar
- Potato
- Pumpkin
- Raspberry
- Redwood
- Rice
- Rose
- Rubber
- Ryegrass
- Sagebrush
- Saltbrush
- Serviceberry
- Sequoia
- Shallot
- Snapdragon
- Sorghum
- Sourwood
- Soybean
- Squash
- Star fruit
- Strawberry
- Succulents
- Sudan grass
- Sugar cane
- Sumac
- Sunflower
- Sweet gum
- Sweet potato
- Sycamore
- Taxus
- Tea
- Tobacco
- Tomato
- Violets
- Wheat
- Yam
- Yucca
- Walnut
- Willow (endo/ecto)

Appendix I

Cultivation Tracking Forms

The following charts are designed to track the major stages of a mycelial lineage and the various factors that influence a cultivation project or experiment. Feel free to adapt these charts to suit your needs. A blank chart is provided to track a variable, such as temperature or humidity levels, over the course of a fruiting cycle.

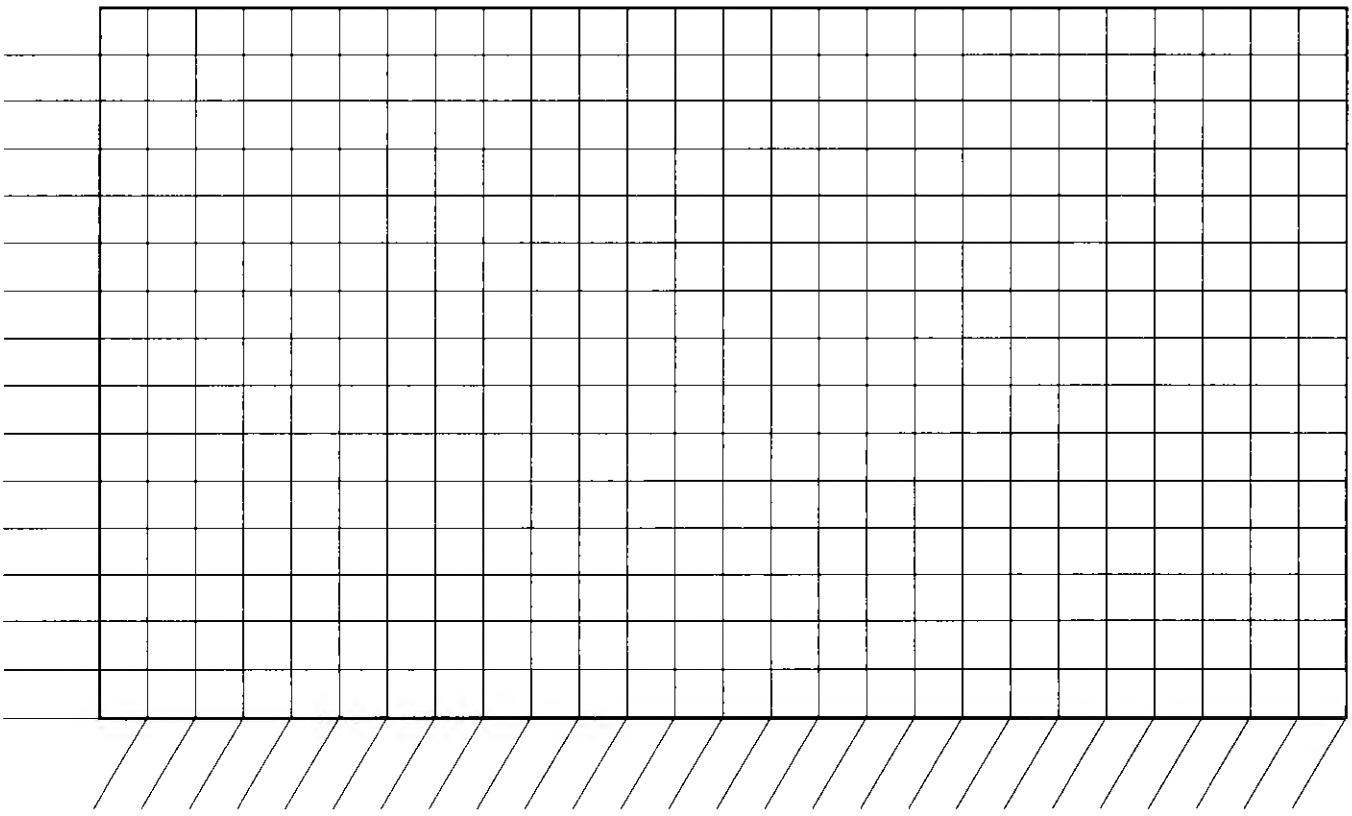
Culture Source			
Project Name			
Species		Strain/Harvest Location	
Tissue Source		Spore Details	
Mycelium Qualities			
Plan of Action			
Acclimation Regimen			
Agar			
Agar Media		Water Quality and pH	
Media Additives		Sterilization Details	
Date Plated		Biodynamic Details	
Inoculation Notes			
Mycelium Qualities			
Plate Division History and Plan			
Contamination Notes			
Liquid Media			
Liquid Media		Water Quality and pH	
Media Additives		Sterilization Details	
Date Inoculated		Biodynamic Details	
Inoculation Notes			
Mycelium Qualities			
Contamination Notes			

Grain Preparation			
Grain Spawn Formula			
Grain Preparation Details			
Grain Inoculation			
Grain Spawn Inoculation Date		Biodynamic Details	
Temperature		Lighting	
Inoculation Notes			
Date of First Shake and Break		Biodynamic Details	
Date Of Full Myceliation		Biodynamic Details	
Date Of Fruiting On Grains		Biodynamic Details	
Contamination Notes			
Myceliation Notes			
2nd Gen Grain Preparation			
Grain Spawn Formula			
Grain Preparation Details			
2nd Gen Grain Inoculation			
Grain Spawn Inoculation Date		Biodynamic Details	
Temperature		Lighting	
Inoculation Notes			
Date of First Shake and Break		Biodynamic Details	
Date Of Full Myceliation		Biodynamic Details	
Date Of Fruiting On Grains		Biodynamic Details	
Contamination Notes			
Myceliation Notes			

Substrate Preparation			
Substrate Formula			
Substrate Source(s)			
Total Dry Weight		Water Quality	
Preparation Details		Substrate Quality	
Moisutre Content		pH	
Hydrated Weight Per Container		Total Hydrated Weight	
Substrate Inoculation			
Spawing date		Biodynamic Details	
Number Inoculated Containers		Temperature	
CO_2		Lighting	
Inoculation Notes			
Date of Full Myceliation		Biodynamic Details	
Contamination Notes			
Myceliation Notes			
Casing Preparation			
Casing Formula			
Moisutre Content		pH	
Casing Preparation Details			
Casing Application			
Casing Application Date		Biodynamic Details	
Temperature		Humidity	
Date Fully Myceliated		Biodynamic Details	
Myceliation Notes			

Primordia Initiation			
Early Pin Set Observations			
Date of Pinhead Initiation		Biodynamic Details	
Temperature		Humidity	
Lighting		Electrical Input	
Primordia Formation			
Date of Pinhead Formation		Biodynamic Details	
Temperature		Humidity	
Evenness of Myceliation		Evenness Of Pin Set	
Casing Moisture Content		Casing pH	
Humidity		Lighting	

Graph Title: _____



Harvesting			
Date of Harvest		Biodynamic Details	
Temperature		Humidity	
1st Flush Weight			
Resting & Dunking Information			
Date of 2nd Flush Initiation		Biodynamic Details	
Temperature		Humidity	
Date of 2nd Flush Harvest		Biodynamic Details	
Days Between 1st and 2nd Flush			
2nd Harvest Weight			
Resting & Dunking Information			
Date of 3rd Flush Initiation		Biodynamic Details	
Temperature		Humidity	
Date of 3rd Flush Harvest		Biodynamic Details	
Days Between 2nd and 3rd Flush			
3rd Flush Weight			
Resting & Dunking Information			
Date of 4th Flush Initiation		Biodynamic Details	
Temperature		Humidity	
Date of 4th Flush Harvest		Biodynamic Details	
Days Between 3rd and 4th Flush			
4th Flush Weight			
Total Harvest Weight		Biological Efficiency	

Total Number of Containers		Average BE Per Container	
Contamination Rate and Notes			
Harvesting and Processing Notes			
Plans For Future Lineages			
Outdoor Application			
Where and How Applied		Biodynamic Details	
Location Details			
1 Month Progress		3 Month Progress	
6 Month Progress		12 Month Progress	
Feeding Regimen		Response To Feeding	
Future Plans			
Spent Spawn			
Notes on Spent Spawn Application			
Medicine Preparation Notes			
Effects of Medicine			

Additional Notes:

Appendix J

Suggested Projects

Prima

- ☐ Build a stir plate.
- ☐ Bulk up Oyster spawn on non-treated sawdust.
- ☐ Bulk up pasteurized sawdust spawn.
- ☐ Create three medicinal products from grain spawn and/or locally harvested mushrooms.
- ☐ Dye fabric with mushrooms or lichens.
- ☐ Fruit Oysters on coffee and cardboard in a 5-gallon bucket.
- ☐ Fruit Oysters on fermented straw in a 5-gallon bucket.
- ☐ Fruit Paddy Straw mushrooms on non-treated straw.
- ☐ Fruit Shiitake on outdoor logs.
- ☐ Fruit Shiitake using the PF Tek.
- ☐ Fruit Turkey Tails from pasteurized sawdust blocks.
- ☐ Identify ten mushrooms based on macroscopic features, spore color, and ecological niche.
- ☐ Inoculate outdoor substrates with a spore spray of local species.
- ☐ Install a King Stropharia wood chip bed.
- ☐ Learn microscopy; measure spores; make a squash mount; and look at mycelial characters (clamps, hyphal types, basidia, cystidia, and gill trama).
- ☐ Make an etching on the underside of an Artist's Conk.
- ☐ Make beer infused with medicinal mushrooms.
- ☐ Make mushroom paper.
- ☐ Make spore print art.
- ☐ Make tempeh, miso, or amazaké.
- ☐ Start a fungal photobook.
- ☐ Start a Grinnell journal.

Segunda

- ☐ Build a bulk pasteurizer and/or sterilizer.
- ☐ Build a fully automated fruiting environment.
- ☐ Build a grey water or microbial water filter.
- ☐ Bulk up naturalized King Stropharia spawn in totes.
- ☐ Collect liquids dripping from a leaking engine on cardboard and inoculate with *Pleurotus ostreatus* or *Pleurotus pulmonarius* in a 5-gallon bucket.
- ☐ Cultivatate *Agaricus blazei* on faux compost.
- ☐ Cultivate indigenous arbuscular mycorrhizal fungi.
- ☐ Cultivate *Trichoderma* soil and compost inoculum.
- ☐ Cultivate *Wolfporia extensa* sclerotia on buried pine logs.
- ☐ Fruit Blewits on spent Oyster straw.
- ☐ Fruit King Oysters from All-in-One Jars.
- ☐ Fruit Reishi in a monotub with pasteurized sawdust as the substrate.
- ☐ Fruit wood-loving species from nutrified sawdust blocks.
- ☐ Grow mycelium into a form.
- ☐ Make blue cheese.
- ☐ Organize and maintain a culture library.
- ☐ Paint or draw a fungus.
- ☐ Set up a paper digester with a local Oyster strain.

Tercia

- ☐ Do a chemical analysis of three strains to determine their medicinal potency.
- ☐ Create 3 fungal spagyrics.
- ☐ Cultivate *Laccaria* mycelium and inoculate a tree with it.
- ☐ Determine the best substrate formula (highest B.E.) for a local mushroom strain.
- ☐ Develop a coffee- or chemical-tolerant strain.
- ☐ Extract laccase and apply it to a chemical. Test the spectra of the chemical before and after and determine if any changes occurred.
- ☐ Fruit Maitake indoors.
- ☐ Fruit Morels (indoors or outdoors).
- ☐ Fruit Shaggy Manes indoors on high quality compost.
- ☐ Grow mycelium into functional products (e.g. insulation, flip flops, bike helmet).
- ☐ Identify a fungus based on its genetics.
- ☐ Make a beer fermented by medicinal mushroom mycelium.
- ☐ Make a scientific illustration of a fungus.
- ☐ Make saké.
- ☐ Propagate *Pleurotus ostreatus* on used cigarette filters.
- ☐ Learn to use an SEM.

Appendix K

Working With Psychoactive Fungi

Preservation of Psiloc(yb)in Mushrooms

Drying

Drying is the best method for preserving psiloc(yb)in mushrooms. A variety of approaches have been devised, one being to lay the mushrooms on a screen or plate in a single layer and set a strong fan to blow over them. Once they are as dry as possible, the mushrooms are packed in a tight fitting jar with fresh desiccant (such as silica), which absorbs any remaining moisture. The mushrooms should not touch the desiccant. Once "cracker dry," the mushrooms are packed in air-tight vessels (vacuum sealing is optional) and stored in the freezer to reduce oxidation and loss of potency. Properly preserved mushrooms can retain their potency for years.

Capsules

Thoroughly dried mushrooms can be finely ground and packed into non-gelatin capsules for long-term storage and measured dosage. Capsules should be stored in airtight containers with desiccant (e.g. silica) packs in the freezer.

Preparing Psychoactive Fungi for Consumption

Psiloc(yb)in Mushrooms

Psiloc(yb)in mushrooms are generally more palatable and potent when fresh. Fresh or dry, the earthy, semi-nutty, dust-like flavor, and distinct "psilocybian" scent of psilocin mushrooms is considered unpleasant by many users. So while the consumption of unadulterated psilocin mushrooms is traditional in Mexico, this approach tends to produce a high incidence of nausea. To mask the mushroom flavor and minimize unpleasant side effects, a variety of preparation methods have been devised.

Tea

Chopped or finely ground mushrooms are added to hot water and steeped for 5-10 minutes to extract the active alkaloids. The addition of high quality tea blends, fresh herbs (e.g. ginger, licorice, mint), and some citrus juice can help mask the mushroom flavor. Once the first cup is consumed, more hot water is used to extract the remaining alkaloids from the mushroom tissue. The mushroom material is then discarded or calcined and added back as refined salts (see Chapter 7).

Nausea is common; some people vomit while others don't. As long as the purging occurs after the mushrooms have been partially digested, the effects will still take hold.

In Food

Psiloc(yb)in mushrooms are commonly incorporated into a variety of foods. Recipes abound on the internet. Example practices include:

- Infusing into wine or strong alcohol.
- Mixing into chocolates or truffles.
- Adding to smoothies, fresh juice, honey, or yogurt.

Vitamin C

The addition of 1–10 grams of water-soluble vitamin C enhances the effect of psiloc(yb)in for many users—sometimes to an unpleasant degree. Likewise, many online users report obtaining a 5–10x potentiation by soaking powdered fruit bodies in lemon and/or lime juice for several hours or days and then drinking the slurry.

MAOIbin

Imitating the South American brew *ayhuasca*, this method of consuming psilocin mushrooms incorporates a monoamine oxidase inhibitor (MAOI) to amplify and/or extend the mushroom's effects. Rätsch lists combinations of 3 grams *Peganum harmala* and 3 grams *Psilocybe cubensis* or 2 grams *Peganum harmala* and 1.5 grams *Psilocybe semilanceata* in sage tea.[1] However, many online users suggest 1 gram of mushrooms to start as the effect can be quite intense. *Auricularia* mushrooms are an MAOI. The MAOI is consumed 30 minutes prior to the mushrooms. Consumption of MAOIs can cause serious medical complications when consumed within several days of certain pharmaceuticals (e.g. SSRIs) or various foods (chocolate, fermented vegetables, cured meats, etc.).

Psilocybin Crystallization

High proof ethyl alcohol and other solvents can extract pure psilocybin from *dry* mushrooms. Depending on the strength of the solvent, the extraction may take 6 hours to 3 weeks. Professor Fanaticus recommended triple extractions in boiling 190 proof alcohol (the mushroom tissue should be filtered between extractions while the liquid is still hot). Once extracted, the solvent is evaporated in open air to concentrate the compounds and then cooled first in a refrigerator and then in a freezer to precipitate psilocybin crystals. This method can be done with fruiting bodies, myceliated/spent substrates, or pure mycelium filtered from liquid culture jars. In his book *Psilocybin Production*, Adam Gottlieb suggests a more elaborate version of this method using methanol and assorted lab gear. Doses are measured in micrograms.

Amanita muscaria

Amanita muscaria caps should be dried at 110°F (43°C) until dry. This process volatizes the nauseating muscarine and converts the mushroom's ibotenic acid to musimol. To consume, caps are rehydrated with water or milk. Other methods of preparation include:

- Extracting in vodka.
- Feeding to snails and then eating the snails to avoid nauseating effects.
- Soaking caps in oil, repeating with more fresh caps and the same oil, then applying the oil to the head to anoint.
- Homeopathic preps of the mushroom are used for complaints of the entire nervous system and can cause powerful dreams.

Consumption of urine is required to experience the full effects of *A. muscaria*. Urine may be repeatedly consumed in up to five to six cycles and/or stored for later use.

How to Have a Less-Upsetting Session

The setting, intentions, beliefs, and (sub)conscious desires of the user all influence the effects of psychoactive fungi. The experience of these mushrooms is entirely framed by the container within which it is placed as well as its subsequent integration. That said, the following guidelines are often used to frame a less upsetting experience:

Long Before

- Studying the Trivium will help increase one's ability to critically assess the psychedelic state and its interpretations by others.
- Investigating the subjects of psychology, philosophy, social design, Nature-based spirituality, and ecology (among many others) can help formulate a personal description of the nature of mind and reality, increasing one's ability to deflect imposed beliefs associated with the psychedelic state.

Before

- Ensuring the mushroom species' identity is critical. Many people have unwittingly bought non-psilocin-containing mushrooms that have been injected with LSD or PCP by their dealer. Their resulting experience was less than desirable. Some of the look-alikes to psilocin mushrooms (e.g. *Conocybe* and *Galerina spp.*) contain deadly toxins.
- In the days leading up to the experience, clearing one's mind, calendar, and living spaces of as much clutter and stress as possible is ideal. Any untended aspects of life may become highlighted and distracting during the experience.
- Determining goals, questions, and/or intentions for the experience as well as an integration strategy can help provide a more insightful container for the experience. Intentions for taking psychedelics that emphasize adventure tend to conflict with the ability to access deep personal insights during the experience.
- Determine the logistics of dosage, location, and time of day. Calm, nurturing, and natural environments often support positive experiences.
- Decide whether a helper will share space during the experience. Having a psychedelic-experienced person present to provide calming words during troubling moments can be very helpful, though they may also influence the experience in unforeseen ways.
- Some people like to consume mushrooms in a large group. Such a shared experience can significantly affect the hypersuggestive individual under the influence of psilocin.
- Clear the space and air. Change clothes. Unplug the phone. Arrange desired lighting, scents, and objects of attention. Sound has a big impact on the experience. Silence, rain patter, a crackling fire, and ambient music are calming choices. Loud, chaotic sound is not recommended.
- Consider fasting so as to clear the body and allow for thorough absorption of the active compounds.
- Gather supplies. Suggested items include:
    - Water
    - Simple food
    - Calming herbs
    - Blankets and pillows
    - Appropriate music
    - Non-caffeinated tea
    - Candles or fire source
    - Multiple layers of clothes
    - Questions to ponder or intentions to set
    - Drawing, writing, and/or recording materials
    - Hand lens and/or binoculars, if outdoors

During

- Record ideas if possible.
- Do not drive, climb tall objects, or do anything dangerous.

After

- Avoid excessive stimuli.
- Eat simple foods and drink lots of water. Rest and nurture yourself.
- Analyze and interpret recorded ideas the next day. Process and integrate any emotionally challenging ideas or insights. Consider how you can manifest any tangible ideas into your normal life.
- Do not feel required to share your experience with others.

Appendix L

Psilocin Mushroom Niches

Pscilocin Mushroom Niches

		Substrate				Season				Chemistry						
		Riparian	Grass/Ground	Dung	Wood	Spring	Summer	Fall	Winter	Psilocin	Psilocybin	Baeocystin	Norbaeocystin	Aeruginascin	Sclerotia Formed
Agrocybe	farinacea														
Conocybe	kuehneriana		•							•	•				
	siligineoides														
Copelandia	affinis														
	anomala									•	•				
	chlorocystis									•	•				
	lentisporus									•	•				
	mexicana									•	•				
	tirunelveliensis									•	•				
	tropica									•	•				
	westii									•	•				
Galerina	steglichii									•	•	•			
Gerronema	solidipes														
Gymnopilus	aeruginosus					•									
	braendlei				•		•	•							
	intermedius				•										
	junonius				•										
	lateritius				•										
	liquiritiae				•						•				
	luteofolius				•		•	•							
	luteoviridis														
	luteus				•		•	•							
	purpuratus			•	•					•	•	•			
	sapineus				•										
	subpurpuratus				•										
	validipes				•										
	viridans				•					•	•				

Psilocin Mushroom Niches

		Substrate				Season				Chemistry					
		Riparian	Grass/Ground	Dung	Wood	Spring	Summer	Fall	Winter	Psilocin	Psilocybin	Baeocystin	Norbaeocystin	Aeruginascin	Sclerotia Formed
Hypholoma	gigaspora														
	neocaledonica														
	popperianum														
Inocybe	aeruginascens		●				●	●		●	●	●		●	
	coelestium									●	●	●			
	corydalina		●					●			●	●			
	haemacta									●	●	●			
	tricolor									●	●	●			
Mycena	cyanorrhiza				●						●				
Panaeolina	foenisecii		●				●	●	●		●				
	microsperma														
	rhombisperma														
	sagarae														
Panaeolus	africanus			●		●									
	bisporus			●						●	●				
	cambodginiensis			●						●	●				
	castaneifolius		●								●				
	cinctulus		●	●		●	●	●			●	●			
	cyanescens	●		●						●	●	●			
	fimicola		●	●		●	●	●							
	microsporus														
	moellerianus														
	olivaceus		●				●	●	●		●				
	papilionaceus			●		●	●								
	retirugis														
	rubricaulis														
	sphinctrinus														
	tropicalis			●						●	●				
	venezolanus														
Pholiotina	cyanopus		●							●	●	●	●	●	●
	smithii	●	●			●	●			●	●	●			
Pluteus	atricapillus											●			
	cyanopus									●	●				
	glaucus														

Psilocin Mushroom Niches

		Substrate				Season				Chemistry					
		Riparian	Grass/Ground	Dung	Wood	Spring	Summer	Fall	Winter	Psilocin	Psilocybin	Baeocystin	Norbaeocystin	Aeruginascin	Sclerotia Formed
Pluteus	nigroviridis									●	●				
	salicinus	●			●		●	●			●	●			
	villosus														
Psilocybe	acutipilea														
	angustipleurocystidiata														
	antioquensis														
	aquamarina														
	armandii														
	aucklandii		●												
	aztecorum		●					●							
	azurescens	●	●					●	●	●	●	●			
	baeocystis		●		●	●	●	●	●	●	●	●			
	banderiliensis														
	brasiliensis														
	brunneocystidiata														
	caeruleoannulata		●												
	caerulescens	●	●			●	●			●	●				
	caerulipes				●		●	●		●	●				
	carbonaria														
	collybioides														
	columbiana														
	coprinifacies														
	cordispora														
	cubensis			●		●	●			●	●	●	●		
	cyanescens		●		●			●	●	●	●	●			
	cyanofibrillosa	●						●	●						
	dumontii														
	fagicola														
	farinacea														
	fimetaria		●	●				●		●	●				
	fuliginosa														
	furtadoana														
	galindoi		●							●	●				●
	graveolens		●					●							

Psilocin Mushroom Niches

		Substrate				Season				Chemistry					
		Riparian	Grass/Ground	Dung	Wood	Spring	Summer	Fall	Winter	Psilocin	Psilocybin	Baeocystin	Norbaeocystin	Aeruginascin	Sclerotia Formed
Psilocybe	guilartensis		●								●				
	heimii		●												
	heliconiae										●				
	herrerae														
	hispanica			●							●				
	hoogshagenii		●				●			●	●				
	inconspicua										●				
	indica										●				
	isabelae										●				
	jacobsii										●				
	jaliscana										●				
	kumaenorum										●				
	laurae										●				
	lazoi										●				
	liniformans		●				●	●	●		●				
	mairei										●				
	makarorae				●					●	●				
	mammillata		●		●						●				
	meridensis										●				
	mexicana		●				●	●	●		●				●
	moseri										●				
	muliercula									●	●				
	naematoliformis		●							●	●				
	natalensis														
	natarajanii										●				
	ovoideocystidiata				●	●	●	●			●				
	papuana														
	paulensis														
	pelliculosa		●				●	●	●		●	●			
	pericystis														
	pintonii														
	pleurocystidiosa														
	plutonia									●	●				
	portoricensis														

Psilocin Mushroom Niches

		Substrate				Season				Chemistry					
		Riparian	Grass/Ground	Dung	Wood	Spring	Summer	Fall	Winter	Psilocin	Psilocybin	Baeocystin	Norbaeocystin	Aeruginascin	Sclerotia Formed
Psilocybe	pseudoaztecorum														
	puberula									●	●				
	quebecensis	●	●				●	●		●	●				
	rostrata														
	rzedowskii										●				
	samuiensis		●				●			●	●				
	schultesii														
	semilanceata		●					●			●	●			●
	septentrionalis				●						●	●			
	serbica		●		●						●	●			
	sierrae									●	●				
	silvatica				●			●			●				
	strictipes		●				●	●							
	stuntzii		●		●	●		●	●	●	●	●			
	subacutipilea										●				
	subaeruginascens				●	●	●			●	●				
	subaeruginosa		●		●	●	●			●	●				
	subcaerulipes		●		●					●	●				
	subcubensis		●	●			●			●	●				
	subtropicalis										●				
	tampanensis		●												●
	tasmaniana														
	uruguayensis														
	uxpanapensis										●				
	venenata									●	●				
	villarrealiae		●							●	●				
	weilii		●		●		●	●	●						
	weldenii										●				
	weraroa				●					●	●				
	wrightii										●				
	yungensis		●				●				●				
	zapotecorum		●							●	●				
Rickenella	fibula		●				●	●	●						

Appendix M

Facilitated Mycology

The following are several additional skills that can help facilitate a smooth and functional meeting for groups.

Meeting Member Roles

Group meetings are much more productive and time-efficient when members take on designated roles to ensure that the meeting's topics are addressed and conversation doesn't stray too far from the topic at hand. Common meeting roles include:

Active Transporter *(a.k.a. AT, Facilitator, Anchor, Bottom Liner)*

The AT maintains order in the meeting and generally takes on the most work. Their roles include:

- Sending a meeting reminder.
- Welcoming new people.
- Proposing agenda items and time allotments for each of them.
- Asking for changes or additions to the agenda when the meeting starts.
- Ensuring that the discussion does not digress from the agenda.
- Checking for concerns when proposals are made.
- When an agenda item seems concluded, asking for additional input before moving on.

ATs also ensure that the interpersonal dynamics of the meeting are balanced. They create space for everyone to be heard and included in tasks/projects. By maintaining a general vibe of inclusion and support, the AT upholds the group's longevity by mitigating the potential for tensions, blame, exclusion, or disrespect. As needed, ATs actively request that the more outspoken members respect the group by talking less so that the quieter members feel that they have space to speak up. Anti-oppression trainings (offered by many organizations online and in most cities) help increase awareness around what may be invisible and unhealthy group dynamics.

Note Taker

This person takes notes on each agenda item addressed in the meeting. They track which tasks each member has volunteered to take on as well as which agenda items were not covered and have to be "tabled" for the next meeting. At the end of the meeting the Note Taker summarizes the meeting's outcomes and next steps/tasks for all the group's members. Note Takers also type up and send out the meeting notes to the whole group as soon as possible. To rotate roles throughout the group, the Note Taker could be the next meeting's facilitator.

Time Keeper *(optional)*

This person keeps track of, and periodically announces, the remaining amount of time allotted for each agenda item as well as for the entire meeting.

Vibe Checker *(optional)*

This person pays attention to the overall engagement level of the group. If needed, they suggest taking short breaks so everyone can move their body and refocus.

Stack Keeper *(optional)*

This person keeps track of the order of who wants to talk.

Meeting Agenda Items *(Points of anastomoses)*

Agenda items will vary by group and meeting. The following guidelines help create an effective agenda and enjoyable meeting:

- Start with check-ins.
- Deal with quick and easy issues first.
- Prioritize items based on urgency.
- Include "tabled" items that were not addressed in the previous meeting.
- Have hyphal branches (sub groups) report back on their respective projects, ask for support, or express/address concerns.
- Check in with members that signed up for tasks at prior meetings. Maintain accountability.
- End with an enjoyable item followed by general announcements.

Hand Signals

To increase the efficacy of a meeting, several silent hand signals have been developed that keep interruptions to a minimum:

- **One Hypha:** One finger is raised to signal that a member wishes to be added to the stack of people waiting to speak.
- **Two Hyphae:** Two fingers signal that a member has a direct response to what is being raised and wishes to jump to the top of the stack to increase the efficacy of the meeting.
- **Wild Mycelium:** This form of silent applause signals that a member is in agreement with what is being said.
- **Point of Anastomosis:** This signal is used when the meeting is going off topic, if tensions are rising, or if group dynamics are otherwise affecting a smooth meeting process and need to be addressed.

Another concern with the consensus process is the abuse of the blocking process. To mitigate this issue:

- *Limit blocking to issues that effect the group's mission or are potentially disastrous to the group.*
- *Provide an option for those who do not support a proposal to "stand aside" rather than block.*
- *Require two or more people to block for a proposal to be put aside.*
- *Require the blocking party to supply an alternative proposal or a process for generating one.*

Decision-Making

The following decision-making process works well. The term "consensus" can be amended to meet the decision-making quota your group has agreed to observe.

1. Discuss the issue and surrounding concerns/needs.
2. Summarize conclusions in a succinct proposal and test for consensus.
3. **If YES:** Determine next steps, deligate tasks, set deadlines, and record agreements.
4. **In NO:** Discuss concerns. Ask if the concerned will "stand aside" and agree to disagree but not impede the proposal. If they will, see step 3. If the concerned blocks the proposal, return to step 1 to address the issue in an alternate format.

Event Organizing

Effective event organizing is an art unto itself. That said, here are some tips for getting the most out of your efforts:

Before

- Get the word out early.
- Design, print, and distribute flyers that have the time, date, location, contact information, costs, and description of the event clearly and legibly written.
- Send an announcement to email lists and post on social media and local event calendars.
- Build alliances. Invite relevant organizations, political parties, and NGOs to learn and make connections.
- Send a press release to local news agencies. Determine a press contact in the group that will field questions or interviews from the press.

At the Event

- Collect emails for your group's email list.
- Engage with the audience.
- Provide pamphlets and other promotional materials for free.
- Provide tables for other organizations to promote their work.
- Photograph and document the project.

After the Event

- Send a thank you to the email list and to everyone involved in the project.
- Follow up with the press to connect articles to the group's website.
- Write up a description of the workshop on your group's website.
- Send a follow up press release. Include a printable quote from an attendee and a few high quality photographs.

Appendix N

Online Resources

Fermentation Culture Sources and Resources

International Kefir Community
http://www.torontoadvisors.com/suppliers
An international kefir grains sharing community. Search for grains near you. Some incur a fee.

Cómo Conseguir Kéfir
http://www.lanaturaleza.es/bdkefir.htm
A Spanish site for trading tibicos, milk kefir, and kombucha cultures in the US and many Spanish speaking countries.

Cultures Alive (Australia)
http://www.culturesalive.com.au
Commercial supplier of tibicos, ginger beer plant, and kombucha cultures.

Cultures for Health (USA)
http://www.culturesforhealth.com
Commercial supplier of tibicos, kefir, kombucha, tempeh, and koji cultures.

GEM Cultures (USA)
http://www.gemcultures.com
Commercial supplier of tibicos, kefir, kombucha, and koji cultures.

The Kefir Shop (UK)
http://www.kefirshop.co.uk
Commercial supplier of tibicos, kefir, ginger beer plant, and kombucha cultures.

Kombucha Kamp (US)
http://www.kombuchakamp.com
Commercial supplier of kombucha cultures.

Tempeh.info
http://www.tempeh.info
Commercial supplier of tempeh cultures.

Yemoos
http://www.yemoos.com
Commercial supplier of tibicos, kefir, and ginger beer plant cultures.

Home Winemaker's Manual
http://winebook.webs.com
Free downloadable guidebook by Lum Eisenman.

Winemaking Talk
http://www.winemakingtalk.com/forum
Free discussion forum on winemaking.

Wine Press
http://winepress.us
Free discussion forum on winemaking.

Make Your Own Fuel
http://running_on_alcohol.tripod.com
A great resource on making homemade ethanol for gasoline engines.

General Taxonomy

General Taxonomic Online Resources Index Nominum Genericorum (ING)
http://botany.si.edu/ing
A database of organism names, compiled by the Smithsonian Institute.

International Code of Botanical Nomenclature
http://www.iapt-taxon.org/nomen/main.php
Detailed rules on the naming of organisms.

Integrated Taxonomic Information System
http://www.itis.gov
Taxonomic information on the world's plants, animals, fungi, and microbes.

Mycological Societies, Associations, and Orgs

African Society for Edible & Medicinal Mushrooms
http://www.asemm.org
An organization seeking to increase awareness of working with mushrooms in Africa.

Amazon Mycorenewal Project
http://amazonmycorenewal.org
A volunteer-based organization working to advance the science of mycoremediation and mushroom cultivation in Ecuador and throughout South America.

European Mycological Association
http://www.euromould.org
An association overseeing the advancement of mycology in Europe. Many European countries have their own mycological society that can be found online.

International Mycological Association
http://www.ima-mycology.org
A non-profit representing 30,000 mycologists worldwide, working to further the advancement of the science.

International Mycorrhiza Society
http://www.mycorrhizas.org
A society for the advancement of education, research, and development of mycorrhizal research.

International Society for Human and Animal Mycology
http://www.isham.org
A worldwide organization working to enhance the study and practice of medical and veterinary mycology.

Mycological Society of America
http://msafungi.org
A scientific society dedicated to advancing the various facets of mycology. Publisher of the scholarly journal *Mycologia*.

North American Mycological Association
http://namyco.org
Overarching organization for many mycological clubs and associations in North America.

North American Truffling Society (NATS)
http://www.natruffling.org
Based in Corvallis, Oregon, NATS works to support amateur and professional research on belowground fungi.

Fungal Genomics, Phylogenetics, and Taxonomy

Assembling the Fungal Tree of Life
http://aftol.org
A project working to interpret the latest findings of fungal genomics to best understand fungal evolution.

GenBank
http://www.ncbi.nlm.nih.gov/genbank
A genetic sequence database run by the National Institutes of Health. Provides an annotated collection of all publicly available DNA sequences.

Index Fungorum
http://www.indexfungorum.org
The global fungal nomenclator, providing the most current name of around 434,000 fungal species (including yeasts, lichens, chromistan fungal analogues, protozoan fungal analogues, and fossil forms).

Index of Fungi
http://nt.ars-grin.gov/fungaldatabases/index.cfm
A fungal database maintained by the U.S. Department of Agriculture, Agricultural Research Service (USDA, ARS). Includes databases on specimens, literature, nomenclature, and fungal symbiotic relationships.

International Commission on the Taxonomy of Fungi
http://www.fungaltaxonomy.org
An organization working to promote the science of robust fungal taxonomy.

MycoBank
http://www.mycobank.org
Owned by the International Mycological Association, Mycobank documents mycological name changes and associated data, such as descriptions and illustrations. MycoBank works closely with Index Fungorum (above). Many mycological journals require a deposition of taxonomic information in MycoBank prior to publication.

Mycopedia: Encyclopedia of Fungal Genomics and Physiology
http://www.mycopedia.org
An encyclopedia of fungal genomics and physiology.

North American Mycoflora Project
http://www.northamericanmycoflora.org
A project working to track and interpret fungal distribution patterns and phylogenies.

Saccharomyces *Genome Database*
http://www.yeastgenome.org
A comprehensive database on all things related to the genetics of *Saccharomyces cerevisiae*.

Fungal Protection

Fundación Fungi
http://www.ffungi.org
An organization working to advance the research, conservation, and promotion of fungi in Chile.

The Fungus Conservation Trust
http://www.abfg.org
A British organization involved with fungal conservation.

International Society for Fungal Conservation
http://www.fungal-conservation.org
A society promoting the global conservation of fungi through activities, awards, campaigns, meetings, and publications.

Mycorrhiza Resources

International Culture Collection of (Vesicular) Arbuscular Mycorrhizal Fungi
http://invam.wvu.edu
A wealth of information on the collection, identification, and preservation of AM fungi.

Mycorrhiza Network
http://mycorrhizae.org.in/index.php
An organization for those involved in mycorrhizal research.

Fungal Identification

Matchmaker: Mushrooms of the Pacific Northwest (MMPNW)
http://s158336089.onlinehome.us/Ian
A free, downloadable aid to identifying mushrooms.

Mushroom Expert
http://www.mushroomexpert.com
Run by Michael Kuo, this dense site has beginner's pages, tips on photography, identification techniques, keys, and mushroom descriptions with photographs.

Mushroom Observer
http://mushroomobserver.org
A site for amateur and professional mycologists to record observations, help others identify mushrooms, and track distribution patterns.

Mykoweb
http://www.mykoweb.com
Run by Michael Wood, this site includes descriptions of over 400 species and nearly 5,000 photographs.

Pacific Northwest Key Council
http://www.svims.ca/council
The Pacific Northwest Key Council is dedicated to the creation and publication of field keys to the fungi of the Pacific Northwest. Various resources are provide for free.

Roger's Mushrooms
http://www.rogersmushrooms.com
Run by Roger Phillips, this site offers detailed information on 1,660 species of fungi located across Europe and North America.

Trichoderma *Identification*
http://nt.ars-grin.gov/taxadescriptions/keys/TrichodermaIndex.cfm
A great visual guide for identifying *Trichoderma* molds to species.

Fungal Cultivation

Mycotopia
http://mycotopia.net
A free discussion forum on mushroom cultivation and much more.

Radical Mycology
http://radicalmycology.com
Provider of free mycological videos, interviews, documents, and original essays organized by the Radical Mycology Collective.

Shroomery
http://shroomery.org
A free discussion forum on mushroom cultivation and much more.

Supplies

Fungi Equipment
http://www.fungiequipment.com
Seller of industrial mushroom cultivation equipment.

Home Science Tools
http://www.hometrainingtools.com
A great resource for inexpensive laboratory equipment.

Mush Comb
http://www.mushroommachinery.com
Seller of industrial mushroom cultivation equipment.

Myco Supply
http://www.mycosupply.com
Seller of home- to moderate-scale mushroom cultivation equipment.

Out-Grow
http://www.out-grow.com
Seller of home- to moderate-scale mushroom cultivation equipment.

Unicorn Bags
http://www.unicornbags.com
Primary provider of filter patch cultivation bags in North America.

Culture Sources

Agricultural Research Service Culture Collection
http://nrrl.ncaur.usda.gov
One of the largest public collections of microorganisms in the world, containing approximately 93,000 strains of bacteria and fungi.

American Type Culture Collection (ATCC)
http://www.atcc.org
A reputable source of high quality cultures.

Florida Mycology Research Center (FMRC)
http://www.mushroomsfmrc.com
Home of the world's largest mushroom spore bank.

Mycelia
http://www.mycelia.be/en/strain-collection/strain-list
A reputable Beligian spawn and culture source.

The USDA-ARS Collection of Entomopathogenic Fungal Cultures
http://www.ars.usda.gov/Main/docs.htm?docid=12125
A culture collection of insect-attacking fungi.

World Federation for Culture Collections
http://www.wfcc.info
A culture collection of fungi and microbes from around the world.

General Mycological Resources

Cornell Mushrooms
http://ccfb.cornell.edu
http://blog.mycology.cornell.edu
Several entertaining and educational resources from Cornell University in Ithaca, NY.

Cyberliber
http://www.cybertruffle.org.uk/cyberliber
A free electronic library for mycological resources new and old, hosting an array of books and rare journals.

David Moore's World Of Fungi
http://www.davidmoore.org.uk
An educational and entertaining resource provided by mycologist David Moore.

Fungal Valhalla
http://www.cybertruffle.org.uk/valhalla/index.htm
The home of mycology's superheroes.

Tom Volk's Fungi
http://botit.botany.wisc.edu/toms_fungi
Run by mycologist Tom Volk, this entertaining and informative site hosts an array of articles and featured fungi.

Lichen Societies and Associations

American Bryological and Lichenological Society
http://www.abls.org
One of the United States' oldest organizations promoting lichen research.

British Lichen Society
http://www.britishlichensociety.org.uk
A society for amateur and professional lichenologists.

International Association for Lichenology
http://www.lichenology.org
An organization promoting the study and conservation of lichens.

Northwest Lichenologists
http://northwest-lichenologists.wildapricot.org
An organization that facilitates communication, meetings, and field trips among lichenologists in the Pacific Northwest.

The California Lichen Society
http://californialichens.org
A great resource for lichenologists in California.

Lichen Identification

A Collection of Lichen Keys
http://www.bgbm.fu-berlin.de/sipman/keys/default.htm
An impressive collection of lichen keys from around the world.

A Cumulative Checklist for the Lichen-forming, Lichenicolous and Allied Fungi of the Continental United States and Canada
http://www.ndsu.edu/pubweb/~esslinge/chcklst/chcklst7.htm
A list of 5,388 lichen species in 720 genera, with an additional 43 subspecies, 47 varieties, and 3 forms.

Lichenland, NACSE
http://ocid.nacse.org/lichenland
Fun with lichens from Oregon State University, with a great synoptic key.

LIAS – A Global Information System for Lichenized and Non-Lichenized Ascomycetes
http://www.lias.net
A multi-authored, distributed internet project containing information about lichen phylogeny and biodiversity.

Other Lichen Resources

Consortium of North American Lichen Herbaria
http://symbiota.org/nalichens/index.php
A gateway to data resources of interest to the lichen taxonomic and environmental research community in North America.

Lichenology
http://www.lichen.com
A resource-rich site with a great ethnolichenology section.

Lichens and Lichenologists
http://www2.hawaii.edu/~cliff/hmpage.html
An assortment of lichen related resources.

National Lichens and Air Quality Database
http://gis.nacse.org/lichenair
Information on lichens and lichen biomonitoring.

Ways of Enlichenment
http://www.waysofenlichenment.net
A site with essays about lichens and photographs of species from North America.

Appendix O

Salv Age

By Jackson Tegu

Long after the collapse of civilization, fungi work to heal the world.

Salv Age

by Jackson Tegu
a story game
collaborative
2 to 4 players
2 to 3 hours

FACILITATOR'S INTRODUCTION AND PREP INSTRUCTIONS

WHAT THIS GAME IS ABOUT

Mushrooms are really amazing! This game is founded on things that leading mycologists believe real fungi do, with some poetic license. In Salv Age, we collectively play as a network of fungi, trying to remediate a pollution site long after human civilization is gone.

We are one entity with many minds. Timeless. Undying. We see ourselves as stewards of the forest, its creatures, and the land itself. We guide growth, we prune excess, and we restore the movement of Nature's shifting balance. When we are met with an indigestible puzzle, we experiment carefully and always find the answer within ourself.

When playing the game, you'll take turns making choices on behalf of the fungi, use special fungal abilities that move around the table, draw a map together, and imagine and describe a lot of cool stuff. The game's not about winning or losing, it's about thinking like a mushroom and finding out what happens as we collaborate about a non-human-centric future. Sound fun?

TABLE OF CONTENTS

If you're reading this and excited about it, you'll probably be the one facilitating the game. That just means getting the components ready and helping everyone to understand how to play. You'll still get to play like everyone else. When describing the game to people you think might want to play it, use the sections What This Game Is About and Participation Expectations.

This game has a lot of components! There are five pages of play materials to copy out of *Radical Mycology*, or download and print from photographsoflightning.com. If you'd like to use your materials to play more than once, print on heavy card stock. The components include:

- A board you have to assemble together at the start of the game using 1 play sheet per player.
- Little diamond-shaped moving pieces for that board called "spores."
- Two smaller, "side" boards.
- A triangular piece for each of the side boards.
- 18 cards, separated into two decks of 9 each.

In order to play, you'll also need:

- Tape (masking tape is best).
- Pencils.
- Erasers.
- Paper for the map between the play sheets. One side of a grocery-sized paper bag works well.

The Sheets / Board

You'll need to print out a copy of the play sheet for each player, and cut out the blank section at the top of each sheet. The game starts with the players cooperating and figuring out how to tape the sheets together to form the board. You'll need a large blank piece of paper to tape into the middle to act as a map you'll draw together. The lower two sections of the play sheets have lists to follow when a player uses one of the fungal abilities.

Pieces and Spores

Spores are diamond-shaped. Pieces are triangular. Before you play, cut out the four unique spores, bending up the striped point of each one to act as a handle. Then you'll cut out enough copies of the Extend the Mycelial Network spore so every player has one, and bend those handle-points up too. (The symbol on that spore is a group of fine lines crossing over one another. There are two marks on its edge.) If you're playing outside you may want some coins or rocks to tape the spores to so they don't blow away.

There are only two triangular pieces. Cut them out, bend their handle-points up, and attach a little ball of tape to the back of each. The Side Boards section describes where each one starts.

Side Boards

There are two side boards, cut them out. Put the triangular piece with the Observe Human Behavior symbol (see play sheet) in the center square of the Human Population and Happiness side board. Put the triangular piece with the Adapt to Break Down Compounds symbol (see play sheet) in the *compound is an indigestible puzzle* box on the Adapting to Break Down Compounds side board.

Cards

There are two decks of cards, 9 in each deck. Cut them out and keep the decks separate. Color the backs of each deck differently so you don't accidentally mix them together.

Before You Play

Stack all the components off to the side, perhaps on another table, so they won't distract the players. The intro paragraphs and participation expectations to be read aloud require their full attention. Later, the learn-together rules will call for the components to be put on the table.

After You Play

Untape the play sheets from the central map, and devise a way to store everything. Use your worn play sheets with pride—with every instance of play they'll feel more authentically post-collapse!

TO LEARN THE GAME TOGETHER

Begin here.

READ ALOUD

the 3 paragraphs under *What This Game is About* on the previous page. Then,

READ ALOUD

the rest of the rules. They'll explain everything we need to know. Feel free to pass them around if you like, participation optional. When they give us directions, we'll follow them before continuing.

PARTICIPATION EXPECTATIONS

Here are four quick tips which will help us get the most out of our game of Salv Age:

Say What's Obvious

We all have unique brains and what's obvious to you won't be obvious to me, so you don't have to try to be clever. Also, stories are strengthened by small, logical steps, so obvious choices help everyone stay on the same page.

Listen Carefully

The things the other players are adding to the story are the building blocks you'll be using when it comes to your turn, so pay attention. Our human brains love reincorporation. That's when something from earlier in the story comes back again. It always feels like a cool trick.

Don't Correct

Some players will make up things that won't align with your understanding of science. That's okay. It's more important for everyone to have a good time and have equal agency in making the world together than to have the imaginary world in the pretend far future with intelligent mushrooms align perfectly with today's scientific journals.

Veto Freely

Sometimes stories can bring up surprising emotional responses. If anything in the story makes you uncomfortable, please just veto it, no questions asked, and the person who made it up will make up something different to replace it. Your feelings are way, way more important than the game, and making up stuff is easy. Also, if someone vetoes something you put into the story, that doesn't make you a jerk. Just make up something quite different and respect their veto. All the players need to agree to veto things that bug them and respect everyone else's vetoes before moving forward. Everyone in?

Salv Age
continued

STEP BY STEP RULES TO PLAY

It's time for us to put all the components on the table. We can opt to look at them now, or wait for them to be explained before doing so. Many find it fun to leave the two decks of cards as surprises to encounter during play.

WE and YOU

What's with the use of We and You? In these rules the word "We" refers to all of the players, either as they're each asked to make their own choice, or when they share something together as a group. For example, "we'll each pick a word," or "we've got two decks of cards." The word "You" refers to one player as they act or make a choice individually. For example, "on your turn, choose a spore that's on your play sheet."

PLAY SHEETS

It's time for us to each get a play sheet. All the sheets are the same. We don't need to read them now but we can look at them if we like.

The bottom two sections of the play sheets have lists to follow when a player uses one of the fungal abilities. The top section is one slice of the game board. We've got to tape together all of our sheets so that our reference lists point directly at each of us and the game board path forms a loop for the game pieces. Let's work together, making sure everyone is involved. After the sheets are all connected, tape another piece of paper across the back of the central hole to make a big blank area in the middle of the sheets.

Do that now! Come back to read more after the sheets are all taped together. All ready? Then let's take a closer look.

MAP and POLLUTION

The paper taped into the middle is now our blank map, where we'll gradually draw details as we discover them, keeping to a very loose sense of scale.

The first thing that we know about this area is that there is some pollution right in the center, something strange left over from a previous time. Let's draw it in: we'll each choose a word to describe the pollution that has seeped into and sat on the ground since the long-gone human civilization left it here. Using pencils, write all those words crisscrossed over one another in the middle of the blank map. The jumble of words representing the pollution should take up 10% of the map. Maybe you'll choose words like Oily, White, Dry, Flaky, Putrid, or Sweet.

As fungi, we're adept at breaking down compounds, but we haven't been able to break these ones down yet. It'll take some experimenting in order for us to do so.

RIVER and PERCEPTION

Ringing the map is the River of Time, which the little diamond-shaped spores that represent our different capabilities will follow as they flow ever leftwards. Time is different for fungi: years and decades fly by as we stay focused on a task, then a single moment will catch us in sudden complete awareness. These moments are represented by the players' turns. Players take turns one at a time proceeding left around the table.

SPORES and FOREST

There are five types of spores: four are fast-moving and unique, and one is slow-moving and plentiful. Each spore is tied to a fungi ability represented in one of the spore lists.

On your turn you'll choose a spore on your section of the River of Time and move it left one space for each mark on its edge. Don't stop on a space with a spore already on it—move past it to the next available space. If the spore lands on a circle, whoever's sheet it lands on (you or the player to your left) follows that circle's list. Whether or not that happens, you then follow the list for the spore you chose. After you do, your turn is over.

Someone now draws a small forest on the map, about an inch across, adjacent to the pollution. This is the area that the fungi initially know well. When you choose to Extend the Mycelial Network, perhaps you'll draw similarly-sized details: other forests, parts of a larger forest, sections of river, other natural things, or crumbled remnants from the human civilization.

CARDS and HUMANS

We've got two decks with 9 cards each. A card is drawn when a spore lands on a circle in the River of Time. One deck of cards is for Natural Rhythms, marked by a sun, and the other for Human Behavior, marked by a humanoid figure. If you exhaust either deck, shuffle your discards and that becomes the new deck. Time is always circling, patterns emerge, things repeat.

The human civilization is long gone, but some humans are still here. They live simply now, behaving much more like animals, though they probably still use some tools and language. Let's look at the map again. Everyone put their finger on a blank part of the map, drawing a pencil dot there. These are places that the humans move between, or can be found. They can be hard to keep track of, moving so quickly, dying so soon.

HUMANS and ENZYMES

We have two side boards that help us keep track of things in the world around us. The pieces on the side boards are moved as a result of the spore lists and circle lists.

The **Human Population and Happiness chart** allows us to keep a critical eye on the number of humans in the area, and how they're doing. Are more humans better? Are fewer humans better? Does the behavior of happy humans create problems for their environment? These and similar questions are interesting to ponder during play. Let the Human Population and Happiness chart inform your descriptions of the Observe Human Behavior card results.

The **Adapting to Break Down Compounds chart** lets us see how far we've come towards our goal of consuming the pollutants and restoring the health of the environment. Players who use the Adapt to Break Down Compounds spore will update this chart as a part of following its associated list. There's no set measurement, just move the indicator ahead as far as feels appropriate. The indicator piece begins in the box on the left end of the chart. When it reaches the second box our fungal self figures out how to produce the correct digestive enzyme to break down the pollutants, and all players can erase parts of the pollution and illustrate nature returning to the polluted area while they're playing. When the Adapting to Break Down Compounds chart indicator moves into the *finish consuming the pollutants* box, we've completed the game!

DROP SPORES and TAKE TURNS

Right now you'll each take one of the plentiful Extend the Mycelial Network spores and one or two of the unique spores, and hold them 6 inches above the River of Time as it crosses your play sheet. Release them, and after they float down, move them to the closest circles on your play sheet.

Now we're ready to begin taking turns. Any volunteer can go first, choosing one of the spores on their sheet and moving it left one space per mark on its edge.

Who volunteers to take the first turn?

AT THE END OF PLAY

When the game's all over, come back here and read the following paragraph aloud:

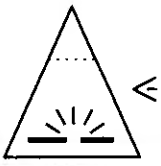
We've won! The ingredients that were long ago taken from the Earth and made incomprehensible to it have once again been translated into something the Earth can use, recycle, and embrace. The compounds that were made strange and distant have become untangled, and their raw materials have been reunited with everything else the Earth breathes, eats, and builds from. Thank you, fungi. You've brought lost fragments back into the dance. And though it's outside of the scope of this game, we'll continue to steward the environment, affect the people around us, and heal the wounds in the world, just like our fungi allies.

CREDITS

Salv Age by Jackson Tegu, first Winter of 2016
This one's for Peter. Thanks for opening my eyes to these wonderful beings and their lessons.
Written in Olympia, in the Cascadia bioregion. This area used to be called Cheetwoot and its plentiful shellfish were gathered by several tribes. Many local changes still to come.
Painting by Erin Sara DiPeso.
Development Team: Peter McCoy, Caroline Hobbs, Marc Hobbs, Robert Bruce, Orion Canning, Erin Sara DiPeso, Ally Mackey, and Ross Cowman.
Editors: Em Stinson, Gary Montgomery, and Marina Valentina.
Big love to The Quiet Year, Avery Mcdaldno, my wonderful patrons, Ymr, A★, Casa Hueso, my blues crew, and Jonny B.
Why games? Games can create a safe sandbox in which to practice communication and provide a too-seldom-found way to imagine together—to share and build. That's why.
Check out more games: photographs of lightning .com

Copy and Cut Out

These five pages have the components for Salv Age!



This piece is for the Adapting to Break Down Compounds side board.

Adapting to Break Down Compounds

finish consuming the pollutants

produce correct digestive enzyme

from here on, description and illustration can
- erase parts of the pollution
- depict nature returning to the polluted area

compound is an indigestible puzzle

description and illustration can
- change what we know about the pollution
- add new details about the pollution

One deck of 9 cards with which to Observe the Natural Rhythms.

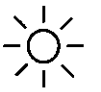
Everything is preparing for sleep. Slowing down, drawing back, closing up.

The humans damage the soil. How, and what are they trying to do?

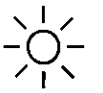
One deck of 9 cards with which to Observe Human Behavior.

The weather is rough and cold. It changes the ground. The wind gusts. Perhaps snow, perhaps rain, perhaps slate gray sky and bone-deep chill.

The young animals are romping around. The young plants are opening up.



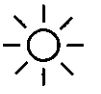
The weather is mild and comfortable. Perhaps sunlight, cloud-shadow, soft rains tickling the soil.



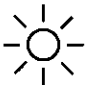
There is too little water and everyone has been thirsty for a long time.

Everything is in bloom. Food is plentiful. An ease permeates the mood.

Scarcity reigns. Not enough food, not enough joy, not enough of what everything needs.



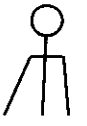
There is much water on the ground, perhaps due to melting snows, perhaps due to rainstorms now passed.



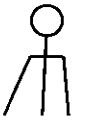
Fertility is in the air, everything is clamoring for one another.

The humans have uncovered and repurposed something dangerous which they don't understand. What?

The humans now worship something else, either in addition to or instead of what they may've already worshiped. What?



The humans have built something, perhaps a structure. What is it?



The humans now clothe themselves differently. How?

The humans are experimenting with a new food or food source. What?

The humans are moving something from one place to another. What, and where?

The humans are embroiled with one another in a conflict of some kind. What are they doing ?

The humans are now carefully damaging something near them. What, and to what end?

(Top of the play sheet)

1. Photocopy these two halves of the play sheet.

2. Cut them out, with the dotted lines removed.

3. Attach the two halves together and photocopy them so they're one play sheet.

Make sure to make a copy for each player!

Alternately, download and print from - - - >

Cut this area out of each player's copy, leaving the black line as a border.

When a spore lands on a circle on your sheet, follow the circle's list before the spore's list:

Observe the Natural Rhythms

The river of time slows for a moment, and you observe where the dance of the seasons has currently found itself.

- Draw a card from the nature deck.
- Describe the effects on the world we know.
- Illustrate a few effects of this change on the map.
- Adjust the Human table if you feel it's appropriate.

Observe Human Behavior

The river of time slows for a moment, and you observe what the humans have been up to recently.

- Draw a card from the human deck.
- Describe their behavior and how it affects their surroundings.
- Illustrate one or two effects on the map.
- Adjust the Human table if you feel it's appropriate.

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(Bottom of the play sheet)

On your turn, select a spore on your sheet and move it left one space for each mark on its edge, then follow its list:

Extend the Mycelial Network

You push your thread-like hyphae into unknown parts of the map, exploring new areas.

- Point to the blank part of the map you're describing.
- Describe what sensations we experience as we move into the area and acclimatize.
- Describe what the area appears like to humans.
- Illustrate the area on the map.

Steward Plants

You gather and redistribute nutrients among the plants that your mycelial network connects and remove heavy metals from the soil.

- Describe how you assist the flora in one area to thrive, and what plants benefit the most.
- Illustrate how an area grows or changes.

Adapt to Break Down Compounds

You experiment to learn which enzymes will digest these strange new pollutants.

- Describe the emotional effort to break down the pollutants.
- Describe a detail or change in the polluted area.
- Illustrate that detail on the map, abiding the rules connected to the Adapting track.
- Move the token on the Adapting track.

Affect Human Brains

You grow a fruit body which contains an aphrodisiac, so the humans procreate readily.

or

You grow a fruit body that teaches the humans a concept through altering their brain chemistry.

- Describe the effects on the humans who consume it.
- Illustrate this human experience on the map.
- Adjust the Human table if you feel it's appropriate.

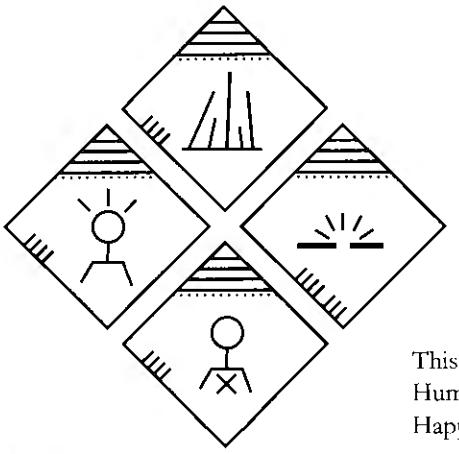
Affect Human Bodies

You grow a fruit body which nourishes and heals the humans, extending and improving their lives.

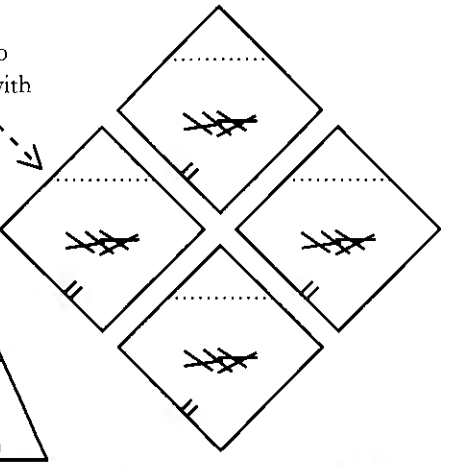
or

You grow a fruit body which poisons the humans, reducing their numbers and happiness.

- Describe the effects on the humans who consume it.
- Illustrate this human experience on the map.
- Adjust the Human table if you feel it's appropriate.

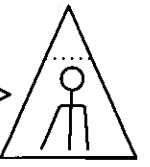


These spores are plentiful. Cut out enough of them so that each player can start with one on their play sheet.



These four spores are unique.

This piece is for the Human Population and Happiness side board.



Human Population and Happiness

many humans

almost none

sickly
depressed

healthy
happy

Appendix P

MycoJokes

What did the young puffball say to the angry older puffball?
Don't be such a spore loser!

Why did the mushroom go to the party?
Because he was a fungi!

Why did the fungi leave the party?
There wasn't enough mushroom!

What kind of soap do mushrooms use?
Ex-Pholiota-*ating body wash.*

Which mushrooms are best at staying up to date on the forest news?
The ones with decurrent gills.

What do hipster *Amanitas* listen to?
Death Cap for Cutie.

Why couldn't the Bolete reproduce?
Its tubes were tied.

How many mycologists does it take to screw in a light bulb?
10. One to screw in the light bulb and 9 to argue about what kind of light bulb it was.

What did the janitor say when his boss told him to clean up the culture spill?
"You Trichlomopsis*!"*

What did the cranky old *Trametes* say to you the young *Trametes* on the upper shelf?
"Quit makin' all that bracket!"

What was Mushroom Jesus's occupation?
A sporocarpenter.

How can you tell when you're turning into Mushroom Jesus?
You get sterigmata on your hands and feet.

What did the mushroom say after being stomped on by an errant, witless child?
"Ouch, my back sure is spore!"

What kind of soda do mushrooms drink?
Fomitopsis piniCOLA!

What did the desert lichenologist yell at the police beating up a group of street kids?
"Don't bust the crust punks!"

What do you call slime-covered travellers that move in packs and eat debris?
Ooglemycota.

Why did the Chicken of the Woods cross the street?
To get to the other pine!

How do you get Chicken of the Woods off?
Laetiporus

What did the Turkey Tail say to the Resihi?
"Wanna take a shelfie?"

What happens when you leave your jacket in my yard?
It becomes mycota.

What grows in the water, eats decaying plants, and has grey gills?
A fish, duh.

What did the zoospore say as it was leaving the zoosporangium?
"After you, I encyst!"

How did the fungus know his partner wasn't a virgin?
Her hymenium was torn.

Why did the Ascomycete refrain from sex for part of its life?
Because sex is a pain in the ascus.

A mushroom walks into a bar.
Bartender says, "We don't serve mushrooms."
Mushroom says, "But I'm a 'fun guy.'"
Bartender says, "I just said we don't serve fungi."
Mushroom says, "No, no, not 'fungi,' 'fun guy.' I made a pun."
Bartender says, "Get the f##k out of my bar."

Two mushrooms fruit on some crap.
The first silly mushroom looks at the second and says, "Hey! This is my pile of crap!"
The second one says, "What? There's plenty of crap for the both of us!"
"No, No," says the other mushroom. "I was here first! This is mine!"
The second mushroom then says, "Wait a minute. Why are we fighting over some dumb s##t? We're mushrooms, not mycologists!"

Mycoticons

```
{-----        (Psilocybe semilanceata)
:(<---))      (Amanita muscaria)
}<---))       (Upturned Amanita muscaria)
8             (Amanita muscaria button)
<------       (Mycena spp.)
<===3         (Phallus impudicus)
{+--•         (Chlorophyllum rachodes)
O             (Calvatia gigantea)
c=))))))))}   (Coprinus comatus)
c======}      (Coprinus comatus, deliquesced)
C=            (Crimini)
•---------0   (Cordyceps capitata)
```

```
==@           (Helvella compressa)
&===          (Helvella maculate)
Q_            (Elephant Reishi)
*             (Earth Star)
(<--}         (Amanita calyptroderma)
&==           (Helvella lacunosa)
O[<           (Geastrum brittanica)
U             (Peziza spp.)
.
|
U             (Cyathus spp.)

^^^^^^^^^^^
   O...
    |         (Psathyrella aquatica)
||
|P
|P            (Fomitopsis pinicola)
||
```

```
 C)       (===      )>--      =)---      ----)<3
c=)       (>--      )===      (----x     {+---
(----     )----     >---      (-<---D
```

```
|
7        (Phellinus cinereus)
|
|

3        (Schizophyllum
3        commune gills, as seen in
3        transverse section)

/\
||
||
||
||
||
||       (Prototaxites)

__
| |---)
| |---)
| |
| |--)
| |
|_|
```

```
#############     (Cubical brown
#############     rotted log)

:::::::           (Spore cloud
::::::: /\        knocking down
::::::: ||        a house)

________          (Bunker bags
 ▯ ▯ ▯            drowning)

XXOOOXXXO         (Fruiting tray of
XOXOXXOXX         Psilocybe
XXXXOXXOX         cubensis,
XOXOXXOXX         as seen from
XXOOOXXXO         above)

    %     (Fruiting oyster log,
  %       as seen from above)
%

{=|===========---------
          (Termitomyces albuminosa)
```

Appendix Q

Latin and Greek Derivations

The following charts contain common prefixes and suffixes used in descriptors of fungi.

Prefixes	Derived From	Meaning
A-, AB-	L	off, from, down, away
A-, AN-	G	not, without, less
ACTIN-	G	a ray, beam, spoke
AD-	L	to, attached to
AER-	G	air
AMPHI-	G	both, about, around
ANA-	L	away, through, again
ANDRO-	G	man, male
ANGIO-	G	a vessel, closed container
ANT-, ANTI-	G	against, away, opposite
ANTE-	L	before
ANTHROPO-	G	referring to man
AP-, APH-, APO-	L	from, off, separate
AQUA-	L	water
ARCHE-, ARCHEO-	L	ancient, primitive
ARTHRI-, ARTHRO-	G	joint, jointed
ASCO-	G	bag, sack, bladder
AUREO-	L	gold colored
AUTO-	G	self
BI-	L	two, twice, double
BIO-, BIOS-	G	related to life
BLASTO-	G	an embryonic layer or cell
BRACHY-	G	short
BRAD-, BRADY-	G	slow, slowness
BRY-, BRYO-	G	moss, mossy
CALIC-, CALIX-	L	cup-like
CANI-, CANIS-	L	dog
CARDIA-	G	heart

Prefixes	Derived From	Meaning
CARN-	L	flesh
CARP-	L	wrist, bones
CATA-	G	decomposition
CELL-	L	small room
CEPHAL-	L	head
CHLORO-	G	green, containing chloride
CHROMA-, CHROMO-	G	colored
CHRON-, CHRONO	G	time
CIRCUM-	L	around, near, about
COEL-	G	hollow cavity, belly
COL-, COM-, CON-	L	with, together
CONTRA-	L	against
CRYPTO-	G	hidden
CYANO-	G	dark blue, blue-green
CYST-	G	bladder
CYT-, CYTE-, CYTO-	G	cell, a hollow vessel
DE-	L	undoing, removal of, from
DEN-, DENT-	L	tooth
DENDRO-	G	tree
DERM-, DERMA-	G	skin, hide
DEUT-, DEUTERO-	G	second, secondary
DI-	G	double, twice, two
DIA-	G	through, across
DIPLO-	G	twofold, double
DIS-	L	apart, away
DORM-	L	to sleep
DROM-, DROME-	G	a running, racing
E-, EC-	L	out, out of

Prefixes	Derived From	Meaning
ECO-	G	house, environment
ECTO-	G	outside
EN-, ENDO-	G	within, internal
ENTERO-	G	intestine
ENTOMO-	G	insect
EO-, EOS-	G	the dawn
EPI-	G	upon, above, top
ERYTHRO-	G	red
EU-	G	proper, true, good
EX-	L	out, from
EXO-	G	outer, external
EXTRA-	L	outside of, beyond
FLAGELL-	L	whip, whip-like
FUC-, FUCO-	G	seaweed, algae, lichen
GAMO-	G	sexual union
GASTERO-, GASTRO-	G	stomach, belly
GE-, GEO-	G	earth
GENO-	L	origin, development
GLU-, GLYCO-	G	sweet, sugar
GON-, GONI-, GONO-	G	reproductive, sexual
GYMN-, GYMNO-	G	naked, bare
GYN-, GYNE-, GYNO-	G	woman, female
HALO-	G	salt
HAPLO-	G	single
HEMI-, HEMO-	G	blood
HEMI-	G	half
HEPTA-	G	seven
HERB-	L	pertaining to plants
HETERO-	G	different, other, unlike
HEX-, HEXA-	G	six
HIPP-, HIPPO-	G	horse
HISTO-	G	tissue
HOLO-	G	whole, entire
HOMEO, HOMO-	G	same, similar, like
HYAL-, HYALO-	G	glassy, transparent
HYDR-, HYDRO-	G	pertaining to water
HYPER-	G	above, more, over
HYPO-	G	below, less, under
ICHTHY-, ICHTHYO-	G	referring to fish
INTER-	L	between
INTRA-	L	within, inside
INTRO-	L	inward, within
ISO-	G	equal, same
KINE-	G	movement, moving

Prefixes	Derived From	Meaning
LEUC-, LEUK-	G	white
LYCAN-	G	wolf
MACRO-	G	large, big, long
MAN-, MANU-	L	hand
MASTIG-	G	whip
MEG-, MEGA-	G	great, large
MELAN-, MELANO-	G	black, dark
MERO-	G	part, piece
MES-, MESO-	G	middle, in between
MET-, META-	G	later, following, changed
MICRO-	G	small
MILLI-	L	a thousandth part
MIO-	G	less, smaller
MITO-	G	thread
MON-, MONO-	G	one, single
MOR-, MORT-	L	die, death
MORPH-	G	shape, form
MUC-, MUCO-	L	consisting of many units
MUS-	L	mouse, as one running
MYCO-, MYKOS-	G	fungus, mushroom
MYO-	G	muscle
MYXO-	G	slime, mucus
NEMATO-	G	thread, threadlike
OB-	L	against
OCTA-	G	eight
OLIG-, OLIGO-	G	few, small, less
OMNI-	L	all, everywhere
OO-	G	pertaining to an egg
OPHTHALMO-	G	referring to the eye
OPISTH-, OPISTHO-	G	behind, backwards, back
ORNI-, ORNITHO-	G	bird
ORTH-, ORTHO-	G	straight
OSTEO-	G	bone
OTO-	G	referring to the ear
OVA-, OVI-, OVUL-	L	egg
PALEO-	G	old, ancient
PARA-	G	beside, near, beyond
PATH-, PATHO-	G	disease, suffer
PED-, PEDI-	L	foot
PENNA-, PINNA-	L	feather, feathery
PENT-, PENTA-	G	five
PER-	L	through
PERI-	G	around, surrounding
PHER-	G	bearing, carrying, support

Prefixes	Derived From	Meaning
PHIL-, PHILO-	G	loving, attracted to
PHOB-	G	fear, fearing
PHOTO-	G	pertaining to light
PHYCO-	G	seaweed, algae
PHYLO-	G	tribe, race, related group
PHYTO-	G	pertaining to plants
PLASM-, PLASMA-	G	formative substance
PLATI-, PLATY-	G	flat
PLEIO-, PLEO-	G	more, many
POD-, PODA-, PODI-	G	foot
POLY-	G	many
POST-	L	after
PRE-	L	before
PRETER-	L	beyond
PRIM-	L	first
PRO-	G	before, on behalf of
PRO-	L	forward
PROTO-	G	first, primary
PSEUDO-	G	0
PSILO-	G	bare, mere
PTERI-, PTERO-	G	fern, feather
QUADR-, QUADRI-	L	four
RADI-	L	ray, spoke of wheel
RE-	L	back, again
RETRO-	L	backward
RHIZ-, RHIZO-	G	pertaining to roots
RHOD-, RHODO-	G	a rose, red
ROTA-	L	wheel
SAPR-, SAPRO-	G	rotten, putrid, dead
SARC-, SARCO-	G	flesh, fleshy
SCHIZ-, SCHIZO-	G	split, splitting
SE-	L	apart
SEMI-	L	half
SOMA-, SOMATO-	G	body
SPERMA-, SPERMATO-	G	seed
SPORO-	G	spore
STAPHYLO-	G	bunch of grapes
STOMA-	G	mouth
STREPTO-	G	twisted, string of
SUB-	L	below, under, smaller
SUPRA-, SUPER-	L	above, over
SYM-, SYN-	G	together, with
TAXI-, TAXO-	G	to make order, arrangement
TEL-, TELE-, TELO-	G	distant, end

Prefixes	Derived From	Meaning
TERRA-, TERRE-	L	land, earth
TETRA-	G	four
THERM-, THERMO-	G	heat
THIGMO-	G	touch
TRANS-	L	across, through, over
TRI-	L	three
TRICHO-	G	hair
TRIPLO-	L	triple
TROCHE-, TROCHO-	G	wheel, hoop
TROPHO-	G	nourishment
ULTRA-	L	beyond, exceedingly
UNI-	L	consisting of one
VICE-	L	in place of
VID-, VIS-	L	see
XEN-, XENO-	G	dry, desert
ZOO-	G	animal, life
ZYG-, ZYGO-	G	to join together

Suffixes	Derived From	Meaning
-BIOSIS	G	mode of living, way of life
-BLAST	G	formative, embryonic
-CHAETA-, -CHETE	G	a bristle
-CHROME	G	color
-CIDAL, -CIDE	L	killer, a killing
-COCCI, -COCCUS	G	round, seed, kernel
-CYST	G	pouch, sac
-DACTYL	G	finger
-DERM, -DERMIS	G	skin, layer
-ELLE, -ULE, -LA, -LE, -LET, -OLE	L	small, diminutive endings
-EMIA	G	blood disease
-FER	L	bearer, producer, carry
-GAMOUS, -GAMY	G	marriage, sexual fusion
-GEN, -GENY	G	origin, production
-GENESIS	L	origin, development of

Suffixes	Derived From	Meaning
-GONY	L	something produced
-GRAPH	G	drawing, writing
-HEDRAL, -HEDRON	G	side
-HYDRATE	G	compound with water
-ISM	G	act, practice or result of
-ITE	L	a division or part
-ITIS	G	inflammation or infection
-JUGAL, -JUGATE	L	to yoke, join together
-LOGY	G	science or study of
-LYSIS, -LYTIC	G	loosening, separation,
-MER, -MEROUS	G	a part, piece
-METER	G	a measurement
-MORPH	G	form
-MYCIN	G	derived from a fungus
-NOMY	G	systematized knowledge of
-OMA	G	tumorous
-OSIS, -OTIC	G	abnormal condition, disease
-PHAGE	G	eater
-PHASE	G	a stage or condition
-PHOR, -PHORE	G	bearing, carrying, supporting
-PHYLL	G	leaf
-PHYTA, -PHYTE	G	plant
-PLASM	G	formative substance
-PLAST	G	organized particle, granule
-POD, -PODA	G	foot
-SOME	G	body
-STASIS	G	a stationary position
-STAT, -STATIC	G	stationary, still
-STOMY	G	opening into
-THERM	G	heat
-THES, -THESIS	G	arrangement, in order
-TOM, -TOMY	G	dividing, surgery
-TROPE, -TROPIC	G	turning
-VOR, -VORE	L	feeding
-ZOA, -ZOAN, -ZOIC	G	animal, life

GLOSSARY

ABSORB: To obtain nutrients by taking up water and dissolved substances across a membrane.

ACCLIMATE: In cultivation, to increase a fungus' preference for a substrate through increasing the substrate's concentration in sequential feeding steps.

ACHLOROPHYLLOUS: Lacking chlorophyll. Unable to photosynthesize.

ACTINOMYCETES: Gram-positive bacteria that often form mycelium-like structures.

AEROBIC: Requiring free oxygen for respiration.

AGARIC: A gill-bearing mushroom.

ALKALINIZE: To raise the pH of a substance, making it more basic/alkaline.

AMORPHOUS: Shapeless, formless.

AMYLASE: An enzyme that hydrolyzes starch.

AMYLOID: Turning blue in iodine.

ANAEROBIC: Cells or organisms that can live without oxygen.

ANAMORPH: The asexual reproductive stage of a fungus' life cycle.

ANASTOMOSIS: To self-fuse together, as when two hyphae connect.

ANION: A negatively-charged ion.

ANNULUS: A ring around the stem of a mushroom, the remains of the partial veil.

ANTHERIDIUM: Sexual structure in ascomycetus fungi containing "male" gametes.

APICAL: Of, or relating to, an apex.

APOTHECIUM: A cup-shaped, spore-bearing structure in Ascomycetes.

APPENDICULATE: Cap margin fringed or adorned with tissue.

APPRESSORIUM: A flattened, hyphal "pressing" organ, used to penetrate plant or animal tissue.

ARBUSCULE: A finely branched organ produced by glomeromycotan fungi inside host root cells. The interface through which a fungus and plant exchange nutrients.

AROMATIC: Conjugated planar ring systems with a delocalized electron cloud.

ASCOGONIUM: Sexual structure in ascomycetan fungi that receives gametes from an antheridium.

ASCOMA (*pl.* ASCOMATA): A multihyphal structure bearing asci, formed by the Ascomycetes.

ASCOMYCOTA: Fungal phylum containing species that form endogenous haploid spores in asci and have a restricted dikaryon.

ASCOSPORE: Haploid spore produced in an ascus.

ASCUS (*pl.* ASCI): The spore releasing structure of Ascomycetes.

ASEPTATE: Used to denote fungi lacking septae (cross walls) inside of their hyphae.

ASEPTIC: Free or freed from contaminating organism(s); working under "sterile" conditions and using "sterile" techniques (e.g. working in

a glove box with flame sterilized inoculating instruments).

Asexual: Here used to refer to the production of spores that have not undergone genetic recombination.

Autoclaving: Sterilization by steam under pressure.

Ballistospory: The forced expulsion of a spore, as observed in basidiomycotan fungi.

Basidiomycota: Fungal phylum containing species that form endogenous haploid spores on basidia and have an extended dikaryon.

Basidiospores: Spores produced on a basidium.

Basidium (*pl.* Basidia): The spore bearing structure of Basidiomycetes; produces exogenous spores (usually 4, sometimes more, occasionally 2) on projections called sterigmata.

Binding hyphae: Thick-walled and frequently branched hyphae, observed in Basidiomycetes.

Binomial: The unique double name given to a species.

Biochar: Carbon-rich charcoal made by pyrolysis.

Biocrusts: A soil level community of mosses, lichens, fungi, and cyanobacteria, commonly found in dryland ecosystems.

Biodynamics: A method of organic farming developed by Rudolf Steiner that employs a holistic understanding of agricultural processes.

Biomonitoring: The measurement of the body burden of toxic chemical compounds, elements, or their metabolites, in biological substances.

Bioreactor: A container used to cultivate fungi in a liquid medium.

Bioremediation: The application of living organisms to remove, reduce, or neutralize contaminants in a polluted environment.

Biotrophic: Growing on another living organism.

Blastocladiomycota: A fungal phyla of microscopic species.

Blight: A general name for many diseases of plants especially when leaf damage is sudden and serious.

Bolete: A fleshy mushroom with tubes under its cap.

Botrytized: Referring to grapes infected with *Botrytis cinerea*, creating a "noble rot" that produces richly flavored wine.

Bracket fungi: Corky or woody, often perennial, polypores of the Basidiomycota.

Brown rot: A wood rot produced by Basidiomycetes that degrades cellulose.

Butt Rot: A rot confined to the roots or base of a tree.

Caespitose: Tufted or clustered.

Calcine: Burn to a fine ash.

Calciphile: Lichens that thrive on calcium-rich substrates (e.g. limestone or calcium-rich soil).

Cation: A positively-charged ion.

Cell: A unit of protoplasm containing a functional genome.

Cellulase: An enzyme that can degrade cellulose.

Cellulose: Principal polysaccharide of plant cell walls; a polymer of glucose.

Cephalodium: Small, gall-like structures found in some species of lichens that contain cyanobacteria.

Chemotropism: Growth of an organism up a chemical concentration gradient.

Chitin: A primary binding polymer in the cell walls of most fungi.

Chlamydospores: A thick-walled and large resting spore.

Chlorolichen: A lichen that contains a green alga as its photobiont.

Chytridiomycota: A fungal phylum of microscopic species.

Clamp Connection: Short, backwardly directed branches on many dikaryotic basidiomycetous hyphae, formed to assist in nuclear division.

Classification: The systematic arrangement of organisms.

Cleistothecium: A globose, completely closed fruit body with no special opening to the outside, as seen in various underground Ascomycetes.

Clone: In cultivation, excising and moving fungal tissue to replicate the organism on a distant substrate.

Common Mycelial Network: A mycorrhizal network that connects multiple plant root systems together.

Complex: A group of closely related fungal species.

Conidiophores: Stalked structure bearing conidia.

Conidium (*pl.* Conidia): Asexual spores produced by Ascomycetes.

Conk: See BRACKET FUNGI.

Coprophilous fungi: Fungi living on dung.

Cortex: In lichens, a dense layer of fungal tissue that prevents water loss.

Cortina: A filamentous or web-like partial veil covering the gills of agarics, commonly seen on *Cortinarius* species.

Crustose: Lichens that grow along or within the surface of their substrate, forming a living skin.

Cryptoendolithic: Literally "hidden inside of rock."

Cyanobacteria: Prokaryotic chlorophyllous organisms often capable of fixing nitrogen. Also known as "blue-green algae."

Cyanolichens: Lichens with cyanobacteria as their primary photobionts.

Cystidium (*pl.* Cystidia): A relatively large cell found on the hymenium of Basidiomycetes. Thought to help regulate humidity levels to assist in ballistospory and/or space gills apart.

Cytoplasm: A thick solution that fills each cell and is enclosed by the cell membrane.

Decay column: A column of discolored or decayed wood inside a tree, often caused by heart rot fungi.

Deliquesce: To liquefy.

Deuteromycetes: An antiquated fungal phyla no longer recognized. Historically used to refer to many asexual fungi in the Ascomycota and Basidiomycota.

Diaspores: A self-cloning structure used by some lichens in which a small "packet" of the species' bionts bud off the main thallus and disperse. Found as isidia or soridia.

Dikaryotic: Having two separate but compatible nuclei in each cell or compartment.

Dimitic: Having two types of mycelium in a fruiting body, almost always as generative and skeletal hyphae.

Ectomycorrhiza: A type of mycorrhizal association in which mycelium forms a mantle around individual rootlets, and grows between cells of the root cortex, forming a Hartig net.

Emergence: The process whereby larger entities, patterns, and regularities arise through the interactions of smaller or simpler entities that themselves do not exhibit such properties.

Endemic: Natural to and always present in one geographical region.

Endolichenic: Inside of a lichen.

Endolithic: In the cracks, fissures, and pores of rocks.

Endomycorrhiza: A type of mycorrhizal association in which mycelia grow between and within root cells.

Endophytic fungi: Fungi that grow systemically within plants without causing symptoms.

Endospore: A dormant, tough, non-reproductive structure produced by a small number of bacteria.

Endosymbiont: An organism that lives in a mutualistic symbiosis within the cells of another organism.

Entomopathogenic fungi: Fungi that act as a parasite of insects and kills or seriously disables them.

Enzyme: A protein that speeds up specific chemical reactions.

Epibiont bacteria: Bacteria that live on the surface of lichens and may play key roles for cell wall function and nitrogen fixation.

Epigenetic: Relating to, or arising from, non-genetic (environmental) influences on gene expression.

Epigeous: Aboveground.

Epihymenium: The thin and often colorful layer above the asci in lichens.

Epilithic: On the surface of rocks.

Epiphytic: On the surface of plants.

Ergosterol: A sterol found in cell membranes of fungi, serving many of the same functions that cholesterol serves in animal cells.

Ethnolichenology: The study of human-lichen relations.

Ethnomycology: The study of fungi in folklore, fiction, and ritual from prehistoric times to the modern era.

Eukaryote: Any organism whose cells contain a nucleus and other organelles enclosed within a membrane.

Ex situ: Off-site.

Exciple: Tissue on the underside and along the rim of an apothecium.

Extremophilic: Capable of thriving in extreme environments.

Fairy ring: Mushrooms arising at the periphery of a radially spreading underground mycelial network.

Family: A group of related genera.

Farinaceous: Cucumber-like smell.

Fermentation: Chemical changes in organic substrates caused by the enzymes and acids of living microorganisms.

Fibrillose: Covered with or composed of fibers.

Field capacity: The maximum amount of water a substrate will hold without draining excess water.

Filamentous: Mycelium-forming.

Flagella: A whip-like structure that allows a cell to move.

Flush: A crop of mushrooms.

Foliose: Leaf-like form observed in lichens.

Foxfire: Bioluminescence created by fungi in decaying wood.

Fractional sterilization: See TYNDALLIZATION.

Fruit body: A multicellular structure on which spore-producing structures, such as basidia or asci, grow.

Fruiting substrate: The substrate from which fruit bodies form, as opposed to a spawning substrate.

Fruticose: A lichen form characterized by a shrubby or bushy growth structure.

Fungi (*sing.* **Fungus**): Non-photosynthesizing (i.e. heterotrophic) eukaryotes that produce exoenzymes and absorb their food. Usually producing, and living inside, a network of apically extending, branched tubes (hyphae).

Fungi Imperfecti: An obsolete name for asexual fungi.

Galvanotropism: The directional growth of an organism in response to an electrical stimulus.

Generative hyphae: Non-branched or rarely branched hyphae.

Genus (*pl.* **Genera**): A principal taxonomic category that ranks above Species and below Family.

Geomycology: The impact of fungi on geological processes.

Glomeromycota: Fungal phylum containing species that form endogenous multinucleate spores and arbuscular mycorrhizal symbioses.

Gymnothecium: A completely enclosed structure containing globose or pear-shaped, deliquescent asci.

Haploid: A cell that has half the total number of chromosomes required for reproducton.

Hartig net: The intercellular hyphal network formed by ectomycorrhizal fungi.

Heart rot: Decay of the inner wood of trees.

Hemibiotrophic: An organism that is parasitic in living tissue for some time and then continues to live in dead tissue.

Hemicellulose: Any of several heteropolymers (matrix polysaccharides) present in plant cell walls.

Heterokaryotic: A multinucleate cell that contains genetically different nuclei.

Homokaryotic: A multinucleate cell that contains genetically identical nuclei.

Horizontal transmission: The transmission of genes or fungal endosymbionts between individuals that are not in a parent-offspring relationship.

Humanure: Human bodily waste recycled for agricultural purposes via composting.

Hygrophanous: Cap surface changing color significantly as it loses moisture.

Hymenium: A palisade or layer of spore-bearing tissue/cells.

Hypha (*pl.* **Hyphae**): The tubular architectural module of almost all fungi, its wall chitinous in eumycotan fungi, cellulosic in Oomycetes.

Hyphal knot: The first stage in fruit body formation, in which mycelium begins to aggregate into a distinct cluster.

Hyphosphere: The area surrounding a hypha.

Hypogeous: Belowground.

Hypothecium: The tissue below the asci in a lichen apothecium.

Immunomodulatory: Capable of modifying or regulating one or more immune functions.

In situ: Latin for "in its original place."

In vitro: Studies performed with microorganisms, cells, or biological molecules outside of their normal biological context.

In vivo: Studies performed with microorganisms, cells, or biological molecules within their normal biological context.

Incubate: To keep organisms at a suitable temperature so that they properly develop.

Inoculate: To put fungal tissue into a substrate.

Inoculum: Fungal tissue used to inoculate a substrate or to infect a host organism.

Inorganic: Referring to, or denoting, a chemical compound that does not contain carbon.

Inrolled: Cap margin tucked under and up.

Ion: An atom or molecule with a net electrical charge.

Isidia: Finger-like lichen diaspores that grow from within the medulla and push up through the cortex.

KOH: Chemical symbol for potassium hydroxide (potash).

Lichen: A micro-ecosystem-like organism comprised of symbiotic fungi, algae, bacteria, and/or a cyanobacteria.

Lichenicolous fungi: Fungi that grow on the surface of lichens.

Lichenometry: The use of lichen growth rates to approximate the age of rock surfaces.

Ligand: An ion or molecule that binds to a central metal atom to form a coordination complex.

Lignin: A persistent compound in plant cell walls, essential in the formation of wood and bark.

Macroscopic: Big enough to be seen by the naked eye.

Mammilate: Cap shape with a notable nipple-like point.

Mannitol: A common sugar source for filamentous fungi.

Mantle: A dense layer of hyphae enclosing the roots of ectomycorrhizal plants.

Medium: A substance or solution used to culture microorganisms.

Medulla: A fluffy hydrophobic network of hyphae in the interior of a lichen.

Megascience: A subject requiring international collaboration to overcome barriers to the subject's assistance in global security and human well-being.

Mesophilic: Organisms that grow between 50-104°F (10-40°C) (optimally 68-95°F [20-35°C]).

Metabolism: The sum of all chemical processes occurring within a living cell or organism.

Microsporidia: A fungal phyla of microscopic species lacking mitochondria.

MOL: Mycelium of Life.

Mold: Fungi associated with deterioration of food or manufactured goods of organic origin.

Monokaryotic: Having only one type of nucleus.

Monomitic: Being comprised of only one type of hyphae, generally generative.

Morphogenesis: The biological process that causes an organism to develop its shape.

Morphospecies: A species distinguished from others only by its morphology.

Muriform spore: A spore with numerous crossing septae.

Mushroom: A fleshy fruit body, usually stalked and with a cap beneath which gills, fleshy tubes, or teeth are covered with or lined with a hymenium.

Must: Grape juice before or during fermentation.

Mutagen: An agent that increases mutation rates.

Mutualism: A kind of symbiosis in which both or all partners gain from the association.

Mycelial cords: Linear aggregations of parallel-oriented hyphae.

Myceliate: The growth of mycelium over and through a substrate.

Mycelium (*pl.* **Mycelia**)**:** Collective term for hyphae; the vegetative structure of a fungus.

Myceteae: A grouping that contains all fungi. The Fungal Queendom.

Myco-corrosion: The fungal corrosion of inorganic substances.

Mycoaccumulation: The concentration of substances (e.g. heavy metals) in fungal tissue.

Mycobiome: The community of endosymbiotic fungi inside a plant or animal.

Mycobiont: The fungal partner in a symbiotic relationship (e.g. mycorrhiza or lichen).

Mycobiota: The species that comprise a mycobiome.

Mycoherbicide: A preparation of phytopathogenic fungi used to kill weeds.

Mycoinsecticide: A preparation of entomopathogenic fungi used to kill insects.

Mycology: The study of fungi.

Mycomimicry: The mimicking of fungal properties and actions in human systems.

Mycoparasite: A fungus that attacks other fungi. A plant that derives its carbon from a fungus.

Mycophagous: Fungus-eating.

Mycophilia: The love of fungi.

Mycophobia: The fear of fungi.

Mycopsychology: The study of the relationship between human beings and the natural world using mycological and psychological principles.

Mycoregeneration: The application of fungi to support the regeneration of a damaged habitat.

Mycoremediation: The application of fungi to mitigate the impacts of pollutants on an environment.

Mycorrhiza: A symbiotic relationship between a filamentous fungus and the roots of a plant.

Mycorrhizosphere: The area around a mycorrhiza.

Mycose: See TREHALOSE.

Mycoses: (*sing.* **Mycosis**): Diseases of humans or animals caused by fungi.

Mycosystem: The combination of living and non-living elements that comprise a holistic fungal propagation strategy.

Mycotoxins: Fungal secondary metabolites that contaminate food and are poisonous to animals and humans.

Necrotrophic: A parasite that kills its host and then feeds on the dead matter.

Nematophagous: Relating to a fungus that eats nematodes.

Neocallimastigomycota: A fungal phyla of microscopic species.

Nitrophilic: Referring to lichens that thrive in areas impacted by nitrogen pollution (e.g. agricultural areas or bird roosts).

Nucleus: A specialized body within a eukaryotic cell bounded by a membrane and containing chromosomes.

Nutrified: Containing nutrients.

Obligate: Invariably found in a particular situation; here used to refer to fungi that must live in intimate association with a living host.

Oligotrophic: An organism that can live in an environment with very low levels of nutrients.

Oomycota: Phylum of chromistan, fungal-like organisms.

Opportunistic: Fungi which are normally saprobic, but occasionally act as pathogens when conditions favorable to infection arise.

Organic: Referring to, or denoting, a chemical compound that contains carbon.

Ostiole: A small hole or opening through which some fungi release spores.

Outer cortex: A dense layer of hyphae on the surface of a lichen.

Oxidation: The loss of electrons in a molecule, atom, or ion.

Panspermia: The theory that life on Earth originated from microorganisms or chemical precursors of life present in outer space.

Pansporia: The theory that that life on Earth originated from fungal spores present in outer space.

Paraphyses: Filament-like support structures in the fruit bodies of Ascomycetes.

Parasexual: A nonsexual mechanism for transferring genetic material without meiosis or the development of sexual structures.

Partial veil: Membrane enclosing gills in some agarics. After rupture, it may remain as a ring, or annulus, on the stipe.

Pasteurization: The application of heat to kill mesophilic organisms.

Pathogen: An organism that causes disease.

Peloton: The intracellular portion of an orchid mycorrhiza.

Peridium: A protective layer enclosing a mass of spores.

Perithecium: Flask-shaped ascoma with an ostiole.

Permaculture: The conscious design of living systems that incorporates the diversity, stability, and resilience of natural ecosystems.

pH: The hydrogen ion concentration in a solution.

Pheonicoid fungi: Fungi that are associated with burned areas. Also known as pyrophilous fungi.

Phloem: Nutrient-conducting tissue in vascular plants.

Photobiont: The photosynthesizing partner in a symbiotic relationship.

Phototropism: Growth toward a light source.

Phylogeny: The evolutionary history of a kind of organism.

Phytoremediation: The application of green plants to reduce pollution in an environment.

Poikilohydric: Reliant on the environment for water access.

Polymer: A compound made by linking many smaller molecules (monomers).

Polypore: Basidiomycetes in which the hymenium line layers of corky, vertically oriented tubes. See BRACKET FUNGI.

Polysaccharide: A polymer made up of many linked simple sugars (monosaccharides).

Powdery mildew: Fungal growth on plant tissue denoted by a white floury covering consisting of conidia.

Preteiphilous fungi: Fungi commonly found in close proximity to dead animal matter.

Primary mycelium: Mycelium with only one type of nucleus (monokaryotic).

Primordium (*pl.* Primordia): An early state of fruit body development.

Prokaryote: A single-celled organism that lacks a membrane-bound nucleus, mitochondria, or any other membrane-bound organelle.

Psychedelic: Relating to or denoting drugs that produce hallucinations.

Psychoactive: Relating to or denoting drugs that alter brain chemistry and cognitive functions.

Psychrophilic: Extremophilic organisms that are cold-loving, having an optimal temperature for growth at about 59°F (15°C).

Pubescent: Minutely hairy.

Punctate: Dotted with minute points or scales.

Pyrolysis: A thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen.

Qi: The life force of any living thing.

Recurved: Curved up and back.

Reductionism: The belief that every complex phenomenon can be explained by analyzing the simplest, most basic physical mechanisms that are in operation during the phenomenon.

Reticulate: Net-like form; often seen as spore ornamentation or stalk exterior tissue.

Rez effect: The addition of water or nutrients to a substrate to increase fruit body yields.

Rhizomorph: A root-like aggregation of hyphae.

Rust: Plant diseases caused by obligate fungi.

Saccharify: To convert to sugar.

Saprobe: A heterotrophic organism that derives food from dead organisms.

Saxicole: A lichen that grows on rock.

Scabrous: Roughened by scabers.

Sclerotium (*pl.* **Sclerotia**)**:** A firm mass of hyphae normally having no spores in or on it and which may give rise to a fruit body.

Secondary metabolite: Organic compounds that are not directly involved in the normal growth, development, or reproduction of an organism.

Secondary mycelium: Mycelium with only two types of nuclei (dikaryotic).

Senescence: The condition or process of deterioration with age.

Septa (*pl.* **Septae**)**:** A hyphal cross-wall, often hosting a central pore.

Septate: Containing septa.

Sexual: Here used to refer to the production of spores that have undergone genetic recombination.

Silviculture: The practice of controlling the establishment, growth, composition, health, and quality of forests.

Skeletal hyphae: Thick-walled and long, or centrally swollen hyphae.

Slime Mold: See OOMYCOTA.

Smut: Plant diseases, often specific to higher plant sex organs, caused by the Ustilaginales.

Soft Rot: A type of wood decay caused by fungi, often under cold and wet conditions.

Solubilization: To make a substance soluble or more soluble, especially in water.

Soralia: Openings in a lichen cortex through which soredia propagules emerge.

Soredia (*sing.* **Soredium**)**:** Lichen diaspores that lack a protective cortex.

Spagyric: An alchemical medicinal preparation made by separating a substance's constituent parts and then recombining them.

Spawn: Any material hosting mycelium and supporting its growth, used to inoculate other substrates.

Species: The lowest-ranking taxon normally used (though subspecies, variety, and race are subspecific taxa). Individuals very similar in all major respects; often used for organisms that are normally capable of interbreeding.

Spitzenkörper: An organelle-like structure that guides hyphal growth and is unique to fungi.

Spore print: A visible deposit of spores.

Spore: A specialized microscopic propagule, usually an agent of dispersal.

Sporocarp: A multicellular structure on which spore-producing structures are born.

Sporulation: The production and release of spores.

Sterigmata: Slender extensions that connect spores to basidia.

Sterilization: The process whereby all microorganisms and their propagules are killed by exposure to heat (see AUTOCLAVING), radiation, or chemicals, or removed by filtration.

Stipe: A mushroom stalk.

Stipitate: With a stalk.

Strain: A specific genotype of a given fungal species. For mushrooms, a unique dikaryon.

Striate: Marked with lines.

Subbing: See SUBCULTURING.

Subculturing: The movement of myceliated agar to an uninoculated agar plate.

Submerged fermentation: The growth of fungi in liquid media.

Substrate: 1) The food of a fungus. 2) A substance acted on by a fungal enzyme. 3) The material from which a fungus fruits.

Swale: A landscaping feature designed to manage water runoff, filter pollutants, and/or increase rainwater infiltration.

Symbiosis: A state of intimate association or living together.

Systemic: The equal distribution of a substance or organism throughout a body or area.

Systems theory: The transdisciplinary study of the abstract organization of phenomena, independent of their substance, type, or spatial or temporal scale of existence.

Taxonomy: The classification of organisms on the basis of their evolutionary relationship.

Tek: Slang for "technique."

Teleomorph: The sexual reproductive stage of a fungus' life cycle.

Terricole: A lichen that grows on soil.

Thallus (*pl.* **Thalli**)**:** A lichen body.

Tissue: A group of similar cells organized into a structural and functional unit.

Tomentose: Covered with soft hairs.

Totipotent: The ability of a single cell to divide and produce all of the differentiated cells in an organism.

Trama: Specialized hyphal tissue constituting the internal structure of mushroom gills, pore tubes, or spines.

Translocation: The removal of things from one place to another.

Trehalose: A sugar found in many fungi.

Trichogyne peg: The bridge formed between antheridium and ascogonium that enables gamete transfer.

Trimitic: A fruit body containing three types of hyphae.

Tripartite lichen: A lichen with algal and cyanobacterial photobionts.

Truffle: An edible underground fruit body of an Ascomycete.

Truncate: Appearing chopped off at one end.

Tryptamine: A monoamine alkaloid with an indole ring structure and structural similarity to the amino acid tryptophan.

Tyndallization: A process dating from the 19th century for sterilizing substances.

Umami: The fifth flavor, responsible for the richness of animal and fungal products.

Umbilicate: Cap with a small central depression.

Umbonate: Cap furnished with a small bump (umbo).

Universal veil: Membrane totally enclosing some young Basidiomycete agarics. After rupture, it remains as the volva around base of the stipe, and often as scales on the top of the cap.

Uteromycetes: Basidiomycetes with basidioma closed at maturity (i.e. spores not forcibly discharged).

Vascular wilt: Fungal diseases that grow through the water-conducting xylem of a plant.

Vector: An organism that aids in the dispersal of another organism or substance.

Veil: See ANNULUS.

Ventricose: Stalk swollen near the middle.

Vermiculture: The cultivation of worms.

Vertical transmission: The transmission of genes or fungal endosymbionts between individuals that share a parent-offspring relationship.

Viscid: Slimy or sticky when moist.

Volva: A sheath around the base of the stipe in some agarics; remains of a universal veil.

White rot: A wood rot produced by Basidiomycetes that degrades both cellulose and lignin.

Wilt: A plant disease characterized by loss of turgidity and collapse of leaves.

Wort: A plant infusion used to create beer, ale, or lager.

Xerotolerant: Able to grow under dry conditions.

Xylem: Lignified water-conducting tissue in vascular plants.

Yang: In Chinese philosophy, the active/masculine principle of Nature.

Yeast: Fungi that in many cases are unicellular, though some produce hyphae.

Yin: In Chinese philosophy, the passive/feminine principle of Nature.

Zygomycota: A traditional fungal phylum of various micro fungi that is no longer recognized.

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ENDNOTES

INTRODUCTION

1. For a deeper insight into how being uninformed on a subject can be a self-perpetuating cycle, see Wood, J. (1997). Unskilled and Unaware of it: How Difficulties in Recognizing One's Own — Incompetence Lead to Inflated Self-Assessments. *Journal of Personality and Social Psychology, 77*(6), 1121-1134.
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CHAPTER 1

1. Lee, D. et al. (2014). A First Comprehensive Census of Fungi in Soil Reveals Both Hyperdiversity and Fine-Scale Niche Partitioning. *Ecological Monographs, 84*, 3-20.
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3. Words are powerful. They are limits on expression—both internally and externally—and the windows through which we perceive the world, its people, and the fungi. Thus, before one learns to describe the fungi it must be recognized that the Linnaean system, though helpful in many ways, is only one of numerous options that could be used for naming fungi. One should not assume that it is not possible to develop their own personal means of describing the relationships of the world's inhabitants.
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Chapter 3

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117. http://www.onebillionrising.org/

Chapter 4

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3. Pierre-Louis, 184.
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Chapter 6

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5. Katz, 167.
6. Hornsey, I. (2003) *A History of Beer and Brewing.* The Royal Society of Chemistry: Cambridge, 6–7.
7. Dugan, *Fungi in the Ancient World*, 5.
8. Vaughan-Martini, A. & Martini, A. (1995). Facts, Myths and Legends on the Prime Industrial Microorganism. *Journal of Industrial Microbiology, 14*(6), 514-522.
9. Sinclair & Sinclair, 76.
10. Dugan, *Fungi in the Ancient World*, 9.
11. Ibid., 11.
12. Ibid., 8.
13. Ibid., 14.
14. Ibid., 17.
15. Buhner, *Sacred and Herbal Healing Beers*, 31.
16. This recipe is adapted from that found in *Sacred and Herbal Healing Beers*, 27. Used with permission from the author.
17. Okamura, T., Ogata, T. et al. (2001). Characteristics of Wine Produced by Mushroom Fermentation. *Bioscience, Biotechnology and Biochemistry, 65*(7), 1596-1600.
18. Buhner, *Sacred and Herbal Healing Beers*, 71.
19. One I like is the very technical and thorough howtobrew.com by John Palmer. Sandor Katz lays down the brewing process in a simpler, more relaxed way in his book *Wild Fermentation* (Chelsea Green, 2003).
20. For example, see http://homedistiller.org.
21. For example, see http://morebeer.com/brewingtechniques/library/backissues/issue2.3/king.html.
22. This 30-step process is too long to detail here. See Henkel, T. (2005). Parakari, An Indigenous Fermented Beverage using Amylolytic *Rhizopus* in Guyana. *Mycologia, 97*(1), 1-11.
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Chapter 7

1. Dugan, *Fungi in the Ancient World*, 51.
2. Moldy breads were described by the herbalist John Perkinson in 1640.
3. The oldest written record of medicinal mushrooms is a medical treatise from India dating to 3000 BCE.
4. This date is contested. Some modern researchers claim this text holds a much humbler origin and dates to around 200 CE.
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8. The Birch Polypore could have also been used as it is a fire starter in its own right, but Amadou is a much better fire starter.
9. Morgan, 108.
10. Kusari, S. et al. (2014). Rethinking Production of Taxol® (paclitaxel) using Endophyte Biotechnology. *Trends in Biotechnology, 32*(6), 304-311.
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13. Newman, D. & Cragg, G. (2012). Natural Products As Sources of New Drugs over the 30 Years from 1981 to 2010. *Journal of Natural Products, 75*(3), 311-335.

14. Dugan, *Conspectus of World Ethnomycology,* 55.
15. Newman, D. & Cragg, G. (2012). Natural Products as Sources of New Drugs over the 30 Years from 1981 to 2010. *Journal of Natural Products, 75*(3), 311-335.
16. Turbyville, T. et al. (2005). The Anticancer Activity of the Fungal Metabolite Terrecyclic Acid A is Associated with Modulation of Multiple Cellular Stress Response Pathways. *Molecular Cancer Therapeutics, 4*(10), 1569-1576.
    See also, Wijeratne, E., et al. (2003). Cytotoxic Constituents of *Aspergillus terreus* from the Rhizosphere of *Opuntia versicolor* of the Sonoran Desert. *Journal of Natural Products, 66*(12), 1567-1573.
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19. Chang & Miles, 59.
20. Numata, M. & Shinkai, S. (2011). "Supramolecular Wrapping Chemistry" by Helix-Forming Polysaccharides: A Powerful Strategy for Generating Diverse Polymeric Nano-Architectures. *Chemical Communications, 47*(7), 1961-1975.
21. See Rogers, R., *The Fungal Pharmacy.*
22. Bae, E. et al. (1997). Effect of *Lentinus edodes* on the Growth of Intestinal Lactic Acid Bacteria. *Archives of Pharmacal Research, 20*(5), 443-447.
23. As 200mM of ascorbic acid.
24. Konno, S. et al. (2002). Anticancer and Hypoglycemic Effects of Polysaccharides in Edible and Medicinal Maitake Mushroom (*Grifola frondosa* [Dicks.: Fr.] S. F. Gray). *International Journal of Medicinal Mushrooms, 4*(3), 1-11.
25. Chang & Miles, 364.
26. Zhu, W., et al. (2006). Effect of the Oil from *Ganoderma lucidum* Spores on Pathological Changes in the Substantia Nigra and Behaviors of MPTP-Treated Mice. *Di Yi Jun Yi Da Xue Xue Bao, 25*(6), 667-71.
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29. This extraction is traditionally known as a tincture and is safe to drink. You might read in some studies that methanol was used to extract these hydrophobic compounds. Methanol is a very strong solvent that is able to pull out more medicine from the mushroom but as it is toxic, it should not be consumed.
30. Setting up a percolation is a quicker extraction method than simple soaking (maceration). Explanations of how to make a percolation extract can readily be found online.
31. This antioxidant-rich substrate is an excellent alternative to the more common substrate of brown rice.
32. If used in cooking, high temperatures may denature or destroy some of the medicinal properties of the grains. Regardless, I like to use myceliated grains in place of raw grains as the fungus can reduce the gluten and other anti-nutritive properties of grains while adding medicinal benefits. Win-win, if you ask me.
33. Kavanagh (Ed.), 201.
34. Ibid., 156.
35. Wang, F. et al. (2012). Optimization of Submerged Culture Conditions for Mycelial Growth and Extracellular Polysaccharide Production by *Coriolus versiolor. Journal of Bioprocessing & Biotechniques, 2*(4), 1-5.
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38. Pollack, 21.
39. Ibid., 172.
40. Rogers, R., 372.
41. Buhner, *The Secret Teachings of Plants,* 150.

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44. Rogers, R., 92.
45. Buhner, *The Secret Teachings of Plants*, 117.

CHAPTER 8

1. Fukuoka, *Sowing Seeds in the Desert*, 140.
2. Gadd, *Fungi in the Environment*, 93.
3. Zhang, L. (2013). Removal of Chlorine Residual in Tap Water by Boiling or Adding Ascorbic Acid. *International Journal of Engineering Research and Applications, 5*(3), 1647-1651.
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   See also, Anderson, J. et al. (2000). Inactivation of Food-Borne Enteropathogenic Bacteria and Spoilage Fungi Using Pulsed-Light. *Transactions on Plasma Science IEEE, 28*(1), 83-88.
5. http://storeitcold.com.
6. http://people.umass.edu/~dac/projects/ColdSnap/ColdSnap.html.
7. M stands for mol. This chemical measurement is defined as the amount of a substance equal in mass (in grams) to the combined mass of the atoms of the constituent molecules of the substance multiplied by Avogadro's number ($6.02214129(27)\times10^{23}$).
8. http://www.ncbi.nlm.nih.gov/pubmed and https://scholar.google.com/ are two good resources.
9. Chang, S. *Training Manual on Mushroom Cultivation Technology*. Hong Kong: United Nations.
10. Kavanagh (Ed.), 175.
11. Turlo, J. et al. (2010). Relationship Between Selenium Accumulation and Mycelial Cell Composition in *Lentinula edodes* (Berk.) Cultures. *Journal of Toxicology and Environmental Health, 73*(17), 1211-1219.
12. These are sometimes called "ultra pasteurizers." I don't use this term as it can be confusing for beginners.
13. http://www.mycomasters.com/.
14. https://mycotopia.net/topic/6079-airport-re-deux.
15. http://www.gameoflogging.com.
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18. For example, see http://www.instructables.com/id/Building-a-forced-air-composting-system.
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20. See Harris, *Growing Wild Mushrooms*.
21. For example, see https://newspaperbokashi.wordpress.com.
22. A wide variety of books and websites exist discussing the benefits humanure, dry toilets, and composting toilets. For example, see http://humanurehandbook.com and http://www.recodenow.org.
23. Wood-loving species can also benefit from a casing layer. However, many farms do not add a casing to these species as it incurs additional cost and labor. The choice is yours.
24. This system was developed by Roger Rabbits (Marc Keith), a forum administrator for shroomery.org.
25. I suggest going to mycotopia.net and shroomey.org and typing in the search terms "martha, "automated greenhouse," and "grow room" to get a sense of what others have done before investing in a full build.
26. For example, see https://youtu.be/M3IIj2l1zXk.
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    See also, Farooq, M. & Ohga, A. (2014). Vegetative Development of Sparassis crispa in Various Growth Conditions and Effect of Electric Pulse Simulation on its Fruit Body Production. *Advances in Microbiology, 4*(5), 267-274.
    See also, Takaki, K. et al. (2014). Effect of Electrical Stimulation on Fruit Body Formation in Cultivating Mushrooms. *Microorganisms, 2*(1), 58-72.
    See also, Takaki, K. et al. (2007). Application of IES Pulsed Power Generator for Mushroom Cultivation. *2007 16th IEEE International Pulsed Power Conference, 2*, 1253-1256.

Chapter 9

1. Now they average 74.8 days, compared to 33.2 days historically.
2. Fukuoka, *The One Straw Revolution*, 24.
3. Smith, S. *Mycorrhizal Symbiosis (3rd ed.)*, 51.
4. Ibid., 35.
5. Ibid., 49.
6. Fortin, et al., 62.
7. Frey-Klett, P., et al. (2007). The Mycorrhiza Helper Bacteria Revisited. *New Phytologist, 176*(1), 22-36.
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15. Boone, E. (2011). *Mycophilia: Revelations From the Weird World of Mushrooms*. New York, NY: Rodale, 279.
16. http://tumblingcreekfarm.com/.
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20. For example, see http://theselfsufficientliving.com/making-diy-rain-barrels/.
21. See http://www.biochar-international.org and http://seachar.org.
22. Tompkins, 40.
23. Ibid., 43.
24. Phan, C. & Sabaratnam, V. (2012). Potential Uses of Spent Mushroom Substrate and its Associated Lignocellulosic Enzymes. *Applied Microbiology and Biotechnology, 96*, 863-873.
25. See http://www.wilhelmreichtrust.org/.
26. See Tompkins, *The Secrets of the Soil*.
27. Fukuoka, *The One Straw Revolution*, 119.
28. Stamets, *Mycelium Running*, 196.

29. For example, see Jacke, D. (2005). *Edible Forest Gardens: Volume 1.* White River Junction, VT: Chelsea Green Publishing Co.
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37. For example, see Hanko, J. (2001). *Mushroom Cultivation for People with Disabilities.* Bangkok: Food and Agriculture Organization of the United Nations.
38. See http://www.alohaculturebank.com/how-to-grow-mushrooms.html.

CHAPTER 10

1. Singh, 117.
2. Azizi, A. et al. (2013). Vermiremediation and Mycoremediation of Polycyclic Aromatic Hydrocarbons in Soil and Sewage Sludge Mixture: A Comparative Study. *International Journal of Environmental Science and Development, 4*(5), 565-568.
3. http://amazonmycorenewal.org.
4. https://publiclab.org/wiki/balloon-mapping.
5. https://publiclab.org/wiki/spectrometer.
6. http://www.dexsil.com/products/detail.php?product_id=23.
7. http://hanbytest.com.
8. http://www.dexsil.com/products/detail.php?product_id=2.
9. http://www.dexsil.com/products/detail.php?product_id=13.
10. http://www.site-lab.com.
11. King Stropharia is a good candidate species as it is able to withstand the environmental stressors of sun exposure, dessication, and full submersion in water and also has notably dense and strong mycelium. See Taylor, A., et al. (2014). Removal of *Escherichia coli* from Synthetic Stormwater Using Mycofiltration. *Ecological Engineering, 78*, 79-86.
12. Thangadurai et al. (Eds.), 152.
13. Ibid., 153.
14. Singh, 486.
15. Gadd, *Fungi in Bioremediation*, 360.
16. Thangadurai et al. (Eds.), 168.
17. Ibid., 162.
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23. http://www.itrcweb.org/bcr-1/
24. Singh, 498.
25. Ibid., 17.
26. More specifically, the radicals cause demethoxylation, decarboxylation, hydroxylation and aromatic ring opening in lignin. These actions cause the cleavage of ether bonds between lignin monomers, cleavage of propane side chains, and the cleavage of benzene rings to ketoadipic acid, which is then fed into the tricarboxylic acid cycle as a fatty acid. While this process is primarily oxidative, some reduction reactions occur as well.
27. Gadd, *Fungi in Bioremediation*, 53.
28. Ibid., 189.
29. The randomness of the delignification process has made it hard for researchers to accurately determine how exactly the entire process works, leaving some details a bit unclear.
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36. Ibid., 447.
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38. Gadd, *Fungi in Bioremediation*, 449.
39. Thangadurai et al. (Eds.), 106.
40. Gadd, *Fungi in Bioremediation*, 150.
41. Thangadurai et al. (Eds.), 107.
42. Donnelly, P. et al. (1993). Degradation of Atrazine and 2,4-Dichlorophenoxyacetic Acid by Mycorrhizal Fungi at Three Nitrogen Concentrations In Vitro. *Applied and Environmental Microbiology, 59*(8), 2642-2647.
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    See also, Adams, P. et al. (2007) *Trichoderma harzianum* Rifai 129522 Mediates Growth Promotion of Crack Willow (*Salix fragilis*) Saplings in Both Clean and Metal Contaminated Soil. *Microbial Ecology, 54*, 306–313.
    See also, Harman, G. et al. (2004). Uses of *Trichoderma spp.* to Alleviate or Remediate Soil and Water Pollution. *Advances in Applied Microbiology, 56*, 313-330.
49. Gadd, *Fungi in Bioremediation*, 139.
50. Hammel, K. E. (1995). Organopollutant Degradation by Ligninolytic Fungi, p. 331–346. In L. Y. Young & C. E. Cerniglia (Eds.), *Microbial Transformation and Degradation of Toxic Organic Chemicals*. Wiley-Liss, Inc.: New York.
51. Singh, 306.

52. Ibid., 117.
53. Ibid., 121.
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55. Benyus, 19.
56. Singh, 420.
57. Gadd, *Fungi in Bioremediation*, 227.
58. Singh, 38.
59. Ibid., 43-44.
60. Ibid., 84.
61. Ibid., 61.
62. Gadd, *Fungi in Bioremediation*, 257.
63. Ibid., 257.
64. Ibid., 254.
65. See *Mycoremediation* by Singh for extensive information on bioreactor designs.
66. Many examples exist, with one being: Stoilova, I. et al. (2010). Properties of Crude Laccase from *Trametes versicolor* Produced by Solid-Substrate Fermentation. *Advances in Bioscience and Biotechnology, 1*, 208-215.
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71. Gadd, *Fungi in Bioremediation*, 12.
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CHAPTER 11

1. Gleick, 308.
2. This term is borrowed from David Holmgren's book, *Permaculture Principles and Pathways Beyond Sustainability.*
3. Gleick, 130.
4. https://www.johntaylorgatto.com.
5. Social philosophers such as Plato, Calvin, and Hobbes have all noted that social control starts by monitoring and manipulating the inner lives of children. The Prussian system was only the most advanced system of its time to employ this knowledge.
6. Free Skools are volunteer-run organizations found around the world that facilitate the free spread of skills and information to communities of all ages and backgrounds. Look to see if one exists in your area!
7. Allen, D. (2015). *Getting Things Done*. London, UK: Penguin Books.
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13. Rogers, R., 313.
14. If you find yourself cruising the internet in search of stinkhorn porn, you will sooner or later encounter stories about the Hawaiian mushroom whose pheromone-laced smell causes women to have an orgasm. All of these redundant articles and blog posts can be traced back to one vague and un-peer-reviewed study of an undescribed *Dictyophora* species, published as an abstract of a presentation from International Conference on Medicinal Mushrooms. The researchers claim that the stinkhorn's spore slime contains a compound that mimics neurotransmitters released in females during sexual arousal, leading to spontaneous orgasm in some women. Whether the legend of *Mamalu o Wahine* ("women's mushroom") is rooted in Polynesian culture or in the online meme machine is unclear to me. So far, the research has not been rigorous or transparent enough to authenticate the story.
15. Raper, C., 236.
16. http://www.isna.org/faq/frequency.

Chapter 12

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2. Metzner, 96.
3. Ott, 319.
4. Ibid., 290.
5. Irvin, *Astrotheology & Shamanism*, 169.
6. Most studies site psilocybin as the molecule activating these sites as this is what was administered. I am assuming here that psilocin is the active ingredient for reasons previously stated.
7. Powell, 112.
8. This approximation is based on an LD_{50} of 285mg/kg and 1% alkaloid content.
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12. Rätsch, 684.
13. Rogers, R., 108.
14. Ibid., 292.
15. Ibid., 254.
16. United Nations Office on Drugs and Crime. (2012). *World Drug Report 2010*. New York, NY: United Nations.
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18. Ibid., 39-42.
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24. Hancock, 7.

25. Jaynes, 440.
26. Narby, 117.
27. Powell, 15.
28. See Whitehead, N. (2002). *Dark Shamans: Kanaima and the Poetics of Violent Death*. Durham, NC: Duke University Press Books.
29. DMT is naturally produced in the human brain—likely in the pineal gland. About a tablespoon of DMT bathes the human brain and nervous system at all times. While consuming external sources of DMT brings about some of the most powerful psychedelic experiences known, the reason for the internal production of DMT has never been adequately explained by modern science. Because there is a pronounced surge in DMT production at birth and at the moment of death, some have suggested that this chemical is responsible for the production and alteration of states of consciousness. It has been suggested that some humans naturally produce high levels of DMT, thereby causing that person to experience unusual means of perceiving or receiving information about reality.
30. Rush (Ed.), 161.
31. Ibid., 308.
32. Pendell, 285.
33. Sessa, 128.
34. Irvin, *The Holy Mushroom*, 75.
35. Rätsch, 662.
36. Devereux, 111.
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38. Rätsch, 632.
39. Arthur, 44 & 53.
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41. Allegro, 189.
42. Rush (Ed.), 488.
43. Devereux, 97.
44. For example, see *The Entheogen Review, 9*(2).
45. Irvin, *Astrotheology & Shamanism*, 181.
46. Rush (Ed.), 163.
47. Wasson, *Soma*, 341.
48. Wilson, 30.
49. Rätsch, 622.
50. Wilson, 96.
51. Rätsch, 674.
52. Ibid., 647.
53. Metzner, 54.
54. The Anishinaabeg is a broad title for the Odawa, Obijwe, and Algonquin people, all of whom speak the closely related Anishinaabemowin/Anishinaabe languages.
55. Keewaydinoquay, 36.
56. Rätsch, 622.
57. Akin to a werewolf, a were-jaguar is a person who can change into this jungle feline.
58. Rush (Ed.), 467.
59. Ibid., 492.
60. Rätsch, 624.
61. Rush (Ed.), 467.

62. Ibid., 470-471.
63. Náhuatl being the language of the Nahua, Mexica, or Aztec people.
64. Powell, 36.
See also, Rush (Ed.), 494.
65. Ott, 276.
66. The statue is currently on public display at the Museum of Anthropology in Mexico City.
67. Rätsch, 624.
68. Rush (Ed.), 501-502.
69. See http://www.mushroomstone.com.
70. Allegro, 111.
71. Rush (Ed.), 302.
72. Ruck et al., *The Hidden World*, 287.
73. Ruck et al., *Mushrooms, Myth & Mithras*, 119.
74. Ibid., 125.
75. Wasson, *Persephone's Quest*, 253.
76. Ruck & Hoffman, *Entheogens, Myth & Human Consciousness*, 97.
77. Allegro, 79.
78. Wasson, *Persephone's Quest*, 151.
79. Allegro, 133.
80. Ruck et al., *The Hidden World*, 299.
81. Ruck et al., *Mushrooms, Myth & Mithras*, Chapter 11.
82. Irvin, *Astrotheology & Shamanism*, 210.
83. Ruck et al., *The Hidden World*, 13.
84. Allegro, 175.
85. Ruck & Hoffman, *Entheogens, Myth & Human Consciousness*, 112.
86. Rätsch, 632.
87. Allegro, 59.
88. Irvin, *The Holy Mushroom*, 105.
89. Allegro, 50.
90. Allegro, 93.
91. Ibid., 61.
92. Ibid., 152.
93. Ibid., 192.
94. Devereux, 89.
95. Powell, 16.
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101. Wilson, 126.
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114. Ott, 280.

115. Devereux, 82.

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117. Akers, 96.

118. Ibid., 100.

119. Ibid., 101.

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122. Ott, 281.

123. Ibid., 287.

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Appendix C

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Appendix D

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Appendix H

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Appendix K

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Species Profiles: Lichens

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Image Credits

A. Cortés-Pérez (Alonso): C.39*
Alen Lomas: 77 (left)*
Alison Harrington: 272*
AnnaKika: Plate 3*
Anton Rezvyi: N.24*
Arthur Lee: 394 (right)
Ava Arvest: 302 (lower right), 304, 306 (left), 307
Bill Sheehan: C.6*
Bob Embleton: 401*
Bob Zuberbuhler: 18 (top), 385*
Carl Mueller: N.16*
Chris Parrish: L.15*
Christine Braaten: Plate 13*
Damon Brunette: N.2*
Dan Molter: 80, N.11, N.20, N.21, C.14, C.33, Plates 11, 15, 17*
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Daniel Wheeler: 104 (bottom)*
David Elliott: 119 (right)*
Dpotera: 154*
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Ethan Pollack: 19 (all), 20
Erich G. Vallery: 51 (upper right)*
Ernest Bloch: 78
FoodCraftLab: 168*
Geoffroy Grignon: 289 (left)
Glen van Niekerk: N.23*
Gljivarsko Drustvo Nis: C.21*
H.J. Larsen: 409*
Hamilton: C.13*
Hans Dahner: 100 (far left and far right)*
Ivan Rodriguez: 77 (center) *
Jackie Goordial: 46
Jason Hollinger: 51 (bottom right), 117 (left), 125 (all), 128, L.1, L.2, L. 3, L.4, L.6, L.7, L.8, L.9, L.10, L.11, L.13, Plates 34, 36, 38, 39, 41, 42, 43, 44, 46, 47
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Jeff Dooley: 35 (left)
Jon (Cooper): 81 (left) *
Joseph O'Brien: 70*
Joseph Soeller: 393
Judi Thomas: N.14, N.29, Plate 12*
Justin Pierce: C.8*
Karen (oldmanofthewoods): 410*
Karode13: C.24*
Kipp Kruger: 215 (bottom), 219 (top), 230, 231 (both), 237 (all), 238, 240 (both), 241 (top), 243 (both), 244, 245, 249 (side, middle, and top), 252, 257 (top 3), 260 (middle two), 261 (bottom), 263 (right 3), 283 (middle), Plates 21, 27, 31
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Nathan Wilson: N.30, C.40*
OggiScienza: 79 (right) *
Olga Tzogas: 250 (top), 251 (top), 254, 258, 303 (right)
Paul Allison: 421*
Petr Kapitola: 47 (bottom)
PLOS One: 15, 17

Randy Cyr: 55 (middle)*
Richard and Danielle: 104 (top), N.7, C.2, C.15, C.28, C.31, C.37, C.38*
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Sava Krstic: N.31, C.34*
Sarefo: 47 (upper)*
Scot Nelson: 50 (top)*
Sten: 51 (lower left)
Susana_t: 163*
T. Nelson: N.5*
Terri Clements/Donna Fulton: N.10*
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Zaca: 100 (center left and right), 111 (all), 118, 129, N.28, C.23, L.5, Plate 40*
Zack Mikalonis: N.1*

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Contributor Biographies

Willoughby Arevalo is a Radical Mycologist, artist, musician, kitchen wizard, farmer, and educator. He holds a B.A. in Studio Art from Humboldt State University with additional studies in mycology, somatic practices, ethnomusicology, and gender studies. Willoughby teaches about fungi, performs and leads forays regularly at festivals and events around North America and joined the Radical Mycology Collective in 2013. He grows mushrooms at home and in the garden using low-tech methods, subsistence forages, and prepares food and medicine from the harvests. His home communities include Vancouver, BC; Arcata, CA; Dakar, Senegal; and Warwick, QC. His work can be found at www.willoughbyarevalo.com.

Maya Elson is a teacher, naturalist, Radical Mycologist, organizer, and lover of the wild. As one of the founding members of the Radical Mycology network, she's worked on various fungal cultivation and educational projects in Olympia, WA and the San Francisco Bay area over the last 9 years. Amongst many other events, she was a core organizer of the Radical Mycology Convergences in 2011, 2012, and 2014. Maya's other passions are as a campaign organizer with climate justice and wilderness defense struggles. She is an instructor of Mycopermaculture, Fungal Biology, Mycorenewal and Mushroom Identification for both adults and children. She is a core organizer of CoRenewal and the Amazon Mycorenewal Project. She is also currently the program coordinator and a guide for Wild Child Santa Cruz, a nature immersion program for homeschoolers.

Ali Cat. Leeds was born in St. Helena, California. She received her BFA at Pacific Northwest College of Art in Portland, Oregon where she now lives and works as a printmaker at Flight 64, a member-run nonprofit print studio. Her prints mingle the literal and metaphorical to illuminate and comment upon the world around us. Her relief, screen, and letterpress prints span from the carnage of clear-cuts to the beauty of peoples movements.

Nastassja Noell has always loved fungi, but she didn't fall in love with lichens until volunteering at an herbarium in Eastern Washington in 2011. Since then, she has conducted lichen inventories in various habitats in Argentina, the sub-Antarctic province of Chile, the Mid-Atlantic Coastal Plain, and most recently the Great Basin Desert. She has worked for the Omora Ethnobotanical Park, the New York Botanical Garden and the Great Basin Institute. She has a degree in Political Science from DePaul University in Chicago, Illinois and a degree in Lichenology from The Evergreen State College in Olympia, Washington. Nastassja currently lives in Reno, Nevada with her partner, lichenologist Jason Hollinger, and their dog, Marvin.

Like fungi in their ecosystems, **Mara Fae Penfil** creates networks around the world, sharing information and resources about the Fungal Queendom in an effort to stimulate the interconnectedness and resilience within communities. As a member of the Radical Mycology Collective and founder of Female & Fungi, Mara utilizes mycology as a foundation for social and environmental advocacy, helping to empower people through the sharing of history, personal story, and skills based in the sciences and intuition. For more info, visit www.femaleandfungi.com.

Jason Scott is an amateur Mycologist, Ethnobotanist, and Spagyricist who has studied traditional Hermetic Alchemy—from history and philosophy to practice—for the past 4 years. He has a background in Ethnobotany and Plant Medicine that started on the Big Island of Hawaii, and has been carried back with him into his home: the Pacific Northwest. Born and raised in Oregon, Jason has an intrinsic interest in the Fungal Queendom and all of its aspects—from cultivation and mycoremediation, to historical and cultural relationships. He is on an ever-deepening journey of education to understand the practical applications of his interests, and the golden threads that connect them.

Peter Sjöstedt-H is an Anglo-Scandinavian philosopher who specialises in the thought of Schopenhauer, Nietzsche, Bergson, and Whitehead, and within the field of Philosophy of Mind. Peter has a Bachelor's degree in Philosophy and a Master's degree in Continental Philosophy from the University of Warwick, where he was awarded a first class distinction for his dissertation on Kant and Schelling in relation to "intellectual intuition." Peter subsequently became a Philosophy Lecturer in South Kensington, London for six years before returning to the tranquility of westernmost Cornwall with his partner and young son. He is now an independent philosopher, giving talks around Europe whilst writing essays, articles, and a forthcoming thesis. For more information on Peter's work, visit www.philosopher.eu.

As a cultivation hobbyist, **Joseph Soeller** helped spearhead Bay Area Applied Mycology into a registered nonprofit. He also loves working with Reishi for all its functions, medicinal and structural.

Jackson Tegu believes in people and communication. He makes games to present ideas and opportunities to feel things. Some are powerful, some are *hilare freal djoeks*. Jackson speaks about and runs games internationally, always looking for new audiences to design for and new ways to play. See more of his work at www.photographsoflightning.com.

Bonnie Rose Weaver is a farmer, herbalist, artist, and educator working the earth of her hometown, San Francisco, CA. She operates the seed-to-bottle urban apothecary 1849 Medicine Garden, a bridge project teaching urbanites the benefits of locally grown plant medicine. For more information on Bonnie's work, visit www.1849medicinegarden.com and www.bonnieroseweaver.com.

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About the Author

In 2006, PETER (from the Semitic *pitrā*, "mushroom") M[Y]CCOY co-founded Radical Mycology, a grassroots organization that creates and distributes accessible information on the importance of mycology, mushroom cultivation, and mycoremediation. Peter has shared his unique approach to seeing and working with fungi with environmental, social, food, and water rights organizations around the world and he regularly teaches mycology courses across North America. A ceaselessly curious autodidact, artist, mushroom cultivator, and educator, Peter lives in Portland, OR, his hometown in the heart of the mycotopic bioregion of Cascadia.

First page (clockwise from top)

Plate 1: A massive Garden Giant (*Stropharia rugosoannulata*) fruit body. This tenacious mushroom can reach monsterous proportions of up to two feet across. It is also easy to grow.

Plate 2: Distinctly nubby ectomycorrhizal roots, as viewed through a hand lens. The white tips are sheathed in a mantle of symbiotic mycelium that helps the plant access nutrients.

Plate 3: Wool yarn dyed by various mushrooms. With or without mordants, fungi produce a rainbow of colors.

First spread (left, clockwise from top)

Plate 4: The rich red of *Echinodontium tinctorium* was long used by Native Americans to dye fabrics and to create a face paint for battles.

Plate 5: The rugged cap texture of *Psathyrella delineata*.

Plate 6: Turkey Tail (*Trametes versicolor*) fruiting in a Portland, OR neighborhood. This 10-foot tall snag was covered from its top to ground level with this potent medicinal mushroom.

First spread (right, clockwise from top left)

Plate 7: Brilliant blue-green wood decay caused by the Ascomycete *Chlorociboria aeruginascens*, or Blue Elf, in Unist'ot'en Territory. Such unique wood is prized by artisans.

Plate 8: *Hydnellum peckii*, the Strawberries and Cream mushroom. Despite its name and stunning allure, this species is too tough to eat.

Plate 9: Noble bunch rot, caused by *Botrytis cinerea*. This fungus transmutes the grapes' flavor profile, creating the revered qualities of botrytized wine.

Plate 10: A King Bolete (*Boletus edulis*) and Hawk's Wing (*Sarcodon imbricatus*) bounty awaits the frying pan in Telluride, CO.

Plate 11: Gourmet Morel mushrooms (*Morchella spp.*) grow in the spring, often when wildflowers are in bloom.

Plate 12: The delicate purples of *Trichaptum biforme*.

Second spread (left, top to bottom)

Plate 13: *Cerrina unicolor*. For unknown reasons, this small polypore is often covered in moss.

Plate 14: Many blue-staining, red-pored boletes—such as this striking *Boletus haematinus*—tend to be poisonous and should not be eaten.

Second spread (right, top to bottom)

Plate 15: The extreme reticulation of *Rhodotus palmatus*.

Plate 16: Mycelium rules everything around me. At skate parks like Burnside in Portland, OR, skateboarders follow lines to navigate challenges and tackle obstacles across their environment. Riders must silently communicate with each other to avoid collision as their trucks and decks slowly degrade coping and concrete.

Third spread (left, top to bottom)

Plate 17: The Birch Polypore (*Piptoporus betulinus*) is a medicinal conk of antiquity. When young, the soft tissue of this polypore can be eaten.

Plate 18: *Cyathus olla*, one of the many bird's nest fungi. When a rain drop enters the cup, its spores launch out in egg-like peridioles.

Third spread (right, top to bottom)

Plate 19: Straw and hardwood sawdust, foundational substrates for most mushroom cultivation projects.

Plate 20: A backyard crop of *Psilocybe cyanescens* hovers above the Badlands in North Dakota.

This page

Plate 21: Turkey Tail (*Trametes versicolor*) digesting a red pigment inside of a small bioreactor. This species is highly regarded for its ability to degrade dyes and a wide range of persistant aromatic compounds.

Opposite page (clockwise from top left)

Plate 22: Pearl Oyster (*Pleurotus ostreatus*) mushrooms fruiting from a 5-gallon bucket of cardboard and coffee. The lid is normally in place to minimize dessication.

Plate 23: Preparing All-in-One jars with nutrified sawdust and grains.

Plate 24: King Oyster (*Pleurotus eryngii*) fruiting from an All-in-One jar. This jar was prepared, cooked, inoculated, and fruited without the aid of a lab.

Plate 25: A local strain of Reishi (*Ganoderma lucidum*) fruits at Smugtown Mushrooms in Rochester, NY.

Plate 26: Installing a Pearl Oyster (*Pleurotus ostreatus*) mushroom bed in Arcata, CA.

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Plate 27: Cloning a dried Amadou (*Fomes fomentarius*) conk. Dried tissue regenerates best when cleaned in 3% hydogen peroxide (right).

Plate 28: An agar plate overrun with a community of micro fungi. Are they contaminants or art?

Plate 29: Packing a bag of freshly inoculated pasteurized sawdust. Kits like this are a cheap and easy way to bulk up mycelium for installations.

Fifth spread (right, clockwise from top left)

Plate 30: 3-gallon bioreactors like this can rapidly produce medicinal mycelium and fungal metabolites for home use. The media inside of this carboy was tyndallized to acheive sterilization.

Plate 31: A homemade substrate tumbler. This system has another lid modified to load cultivation containers and a third for channelling biogas out of the drum and into a fuel reservoir.

Plate 32: These two jars of liquid inoculum were originally the same color. Piopinno (*Agrocybe aegarita*, right) notably darkens its liquid media due to the release of metabolites.

Plate 33: A humble basement flow hood set up still gets the job done.

Sixth spread (left, clockwise from top)

Plate 34: Leaf-like thalli of *Lobaria pulmonaria*.

Plate 35: *Neuropogon spp.* at Isla Navarino, Chile.

Plate 36: *Acarospora schleicheri* in southern California.

Sixth spread (right, clockwise from top left)

Plate 37: Elegant drapery of *Usnea longissima*.

Plate 38: *Hypogymnia physoides* in Maine.

Plate 39: *Lecanora muralis*.

Plate 40: *Collema tenax*.

Plate 41: *Bryoria fremontii* in the foothills of Alberta, Canada.

Seventh spread (left, clockwise from top left)

Plate 42: *Xanthoria parietina*, a Sunburst Lichen.

Plate 43: *Calicium viride* in eastern Washington state.

Plate 44: *Calicium viride* apotheticia.

Plate 45: *Cetraria ericetorum*.

Seventh spread (right, clockwise from top)

Plate 46: *Rhizocarpon riparium*.

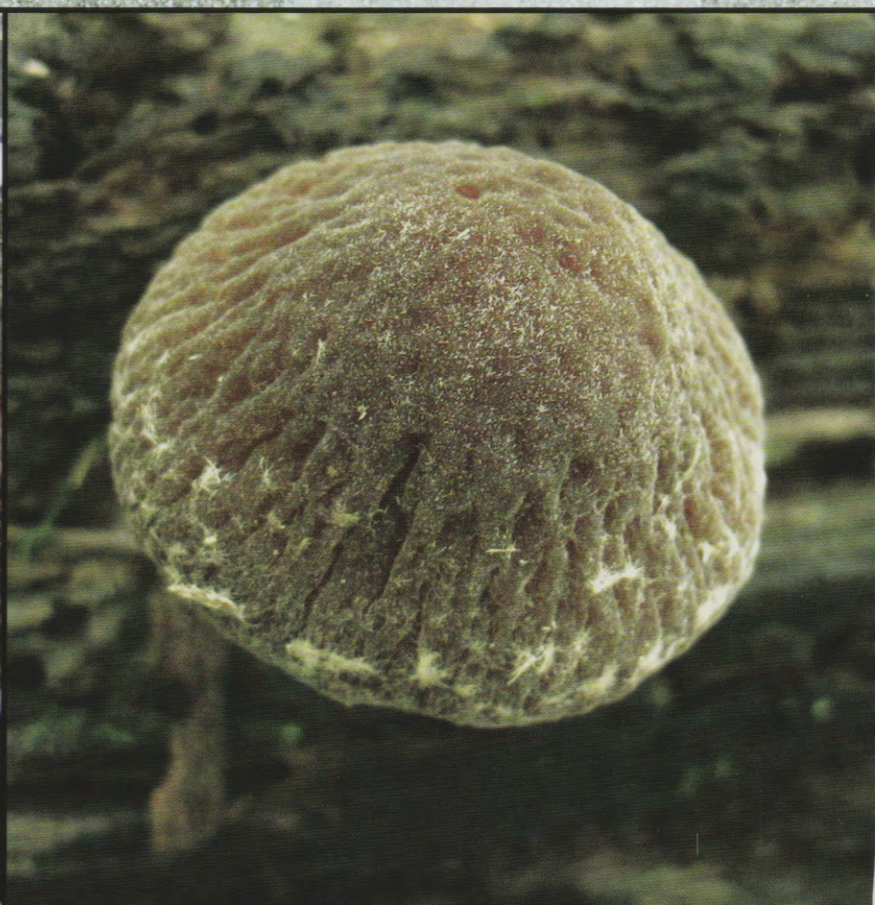
Plate 47: *Lepraria neglecta*.

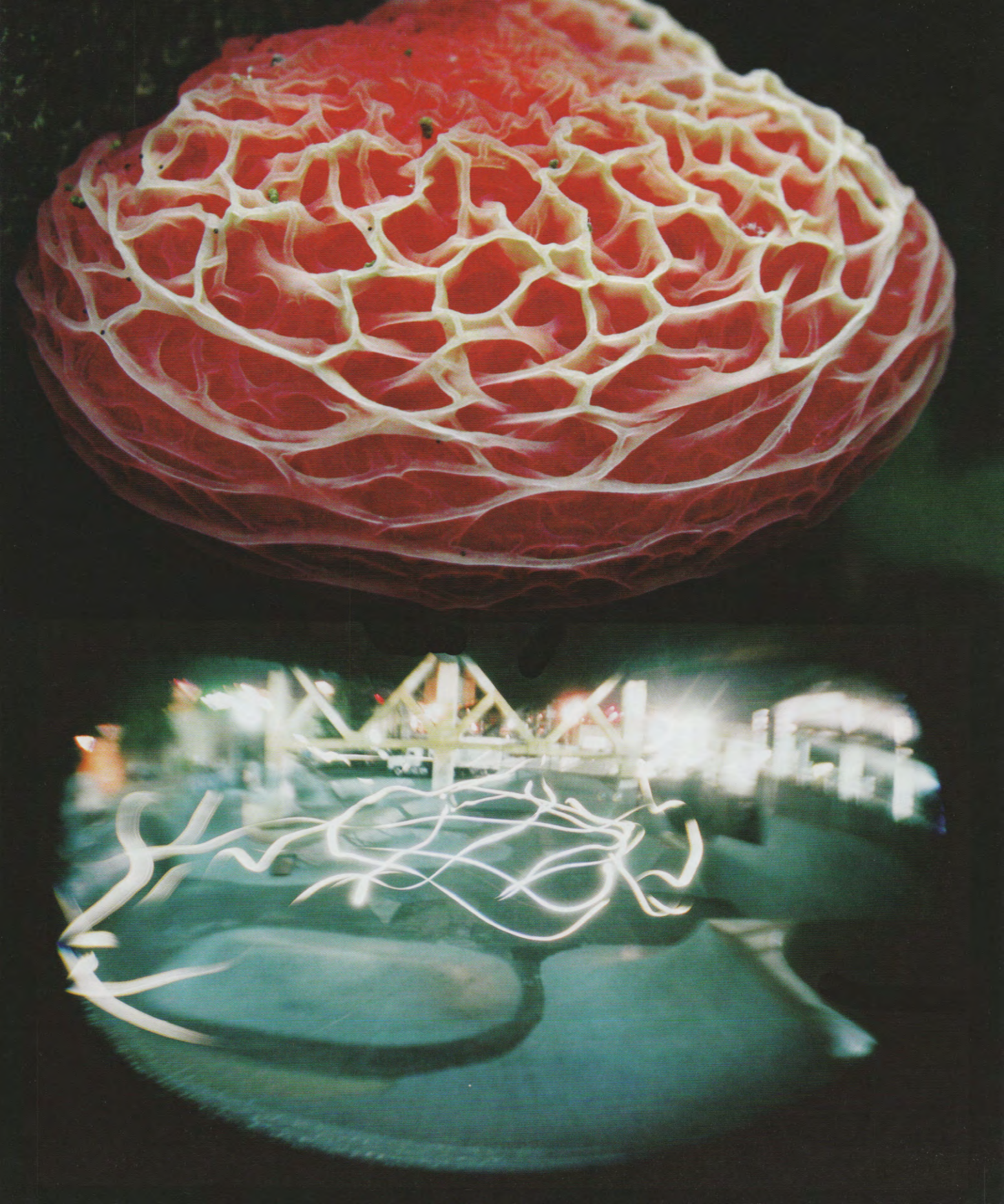
Plate 48: *Lecanora muralis*.

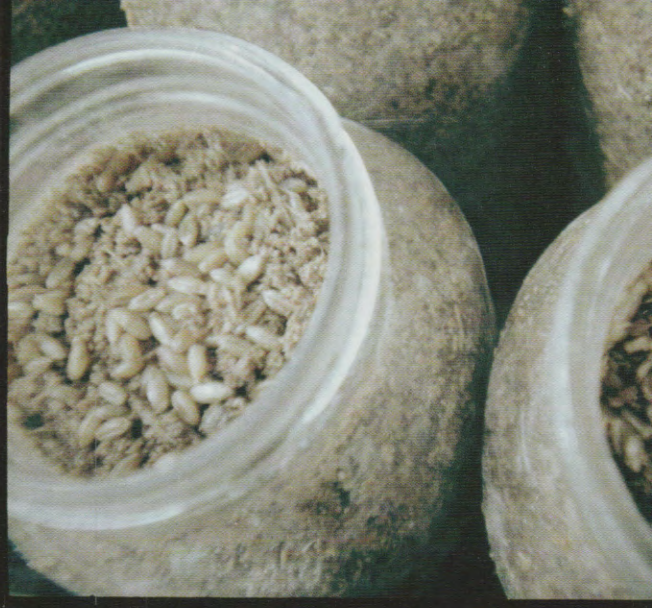
Last page (from top)

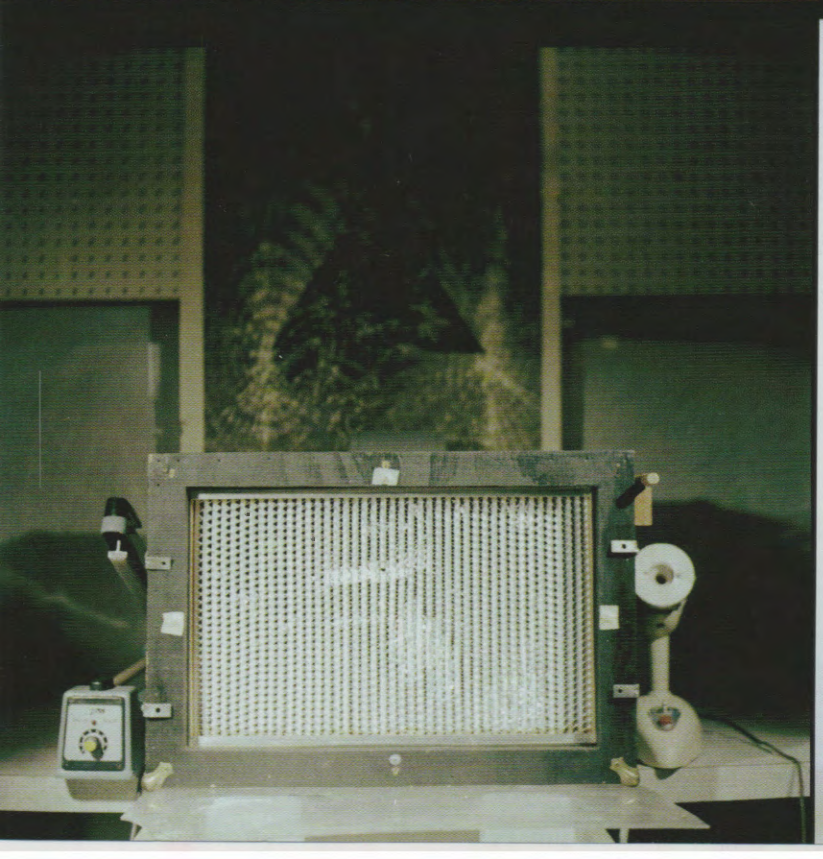
Plate 49: The woody wisdom of Agarikon (*Fomitopsis officinalis*). This slow-growing polypore is primarily found in temperate, old growth rainforests of the U.S. and Europe.

Plate 50: The mycelium is the message.







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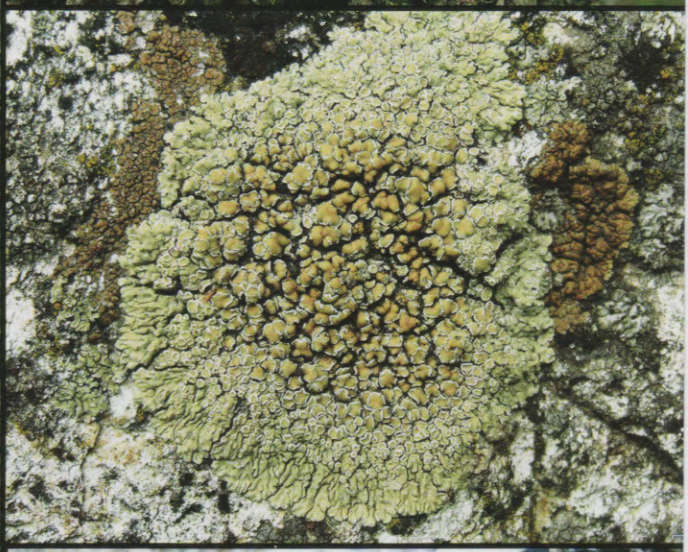


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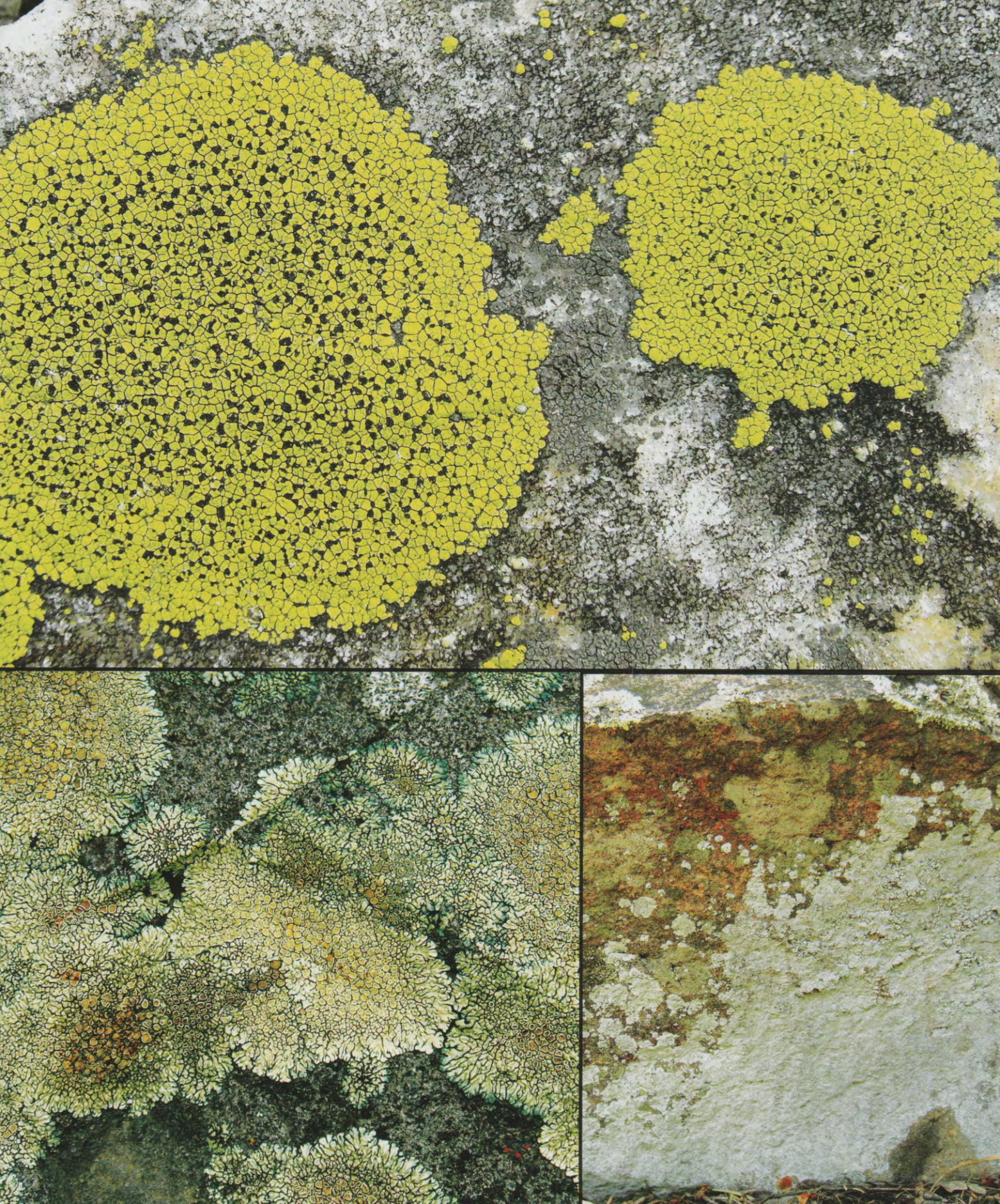

"What an amazing compendium! *Radical Mycology* is filled with provocative ideas and practical information for DIY projects. This is a great resource for anyone fascinated by the ubiquitous world of fungi and wishing to broaden their understanding of this important realm. Be prepared to totally geek out on fungi."

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—**Tao Orion**
author of *Beyond the War on Invasive Species*

"Peter McCoy has given us a bold container. May we digest this substrate and carry our metabolic energy into the field, the forest and the streets, for indeed, *the mycelium is the message.*"

—**Nance Klehm**
author of *The Ground Rules: A Manual To Reconnect Soil and Soul*

Fungi fulfill critical roles at the center of all ecological webs. They manage the flow of nutrients, determine the plant assembly of whole habitats, and profoundly support the health of innumerable species. As culturally important foods and medicines, they have been intimately tied to the development and spread of human societies since prehistory. Today, the cultivation of mushrooms and other fungi offers a seemingly unlimited potential for increasing the resilience of human communities and the environment. And yet, mycology—the study of fungi—is the most overlooked field of natural science.

In *Radical Mycology*, Peter McCoy provides answers to dispelling this paradox. After starting with a thorough examination of fungal biology, ecology, and historical importance, McCoy dives into the many ways to engage with and understand the vast world of fungi. Step-by-step methods for making high quality medicinal mushroom extracts, easily identifying and cultivating mushrooms and lichens, mitigating pollution via mycoremediation, growing fermenting and mycorrhizal fungi, and much more are provided alongside hundreds of descriptive photographs and illustrations. Throughout this extensive journey, McCoy also offers his personal insights into the unique gifts of fungi gleaned from his 15 years of cultivating mushrooms and studying their historical impacts.

Written for the beginner as well as the experienced mycologist, *Radical Mycology* is an in-depth reference and resource manual for anyone interested in the growth of mycology as a people's science. More than a book on mushrooms, *Radical Mycology* is a call to ally with all fungi in any effort to spawn a healthier world.

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