MYCELIUM RUNNING

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How Mushrooms Can Help Save the World

PAUL STAMETS

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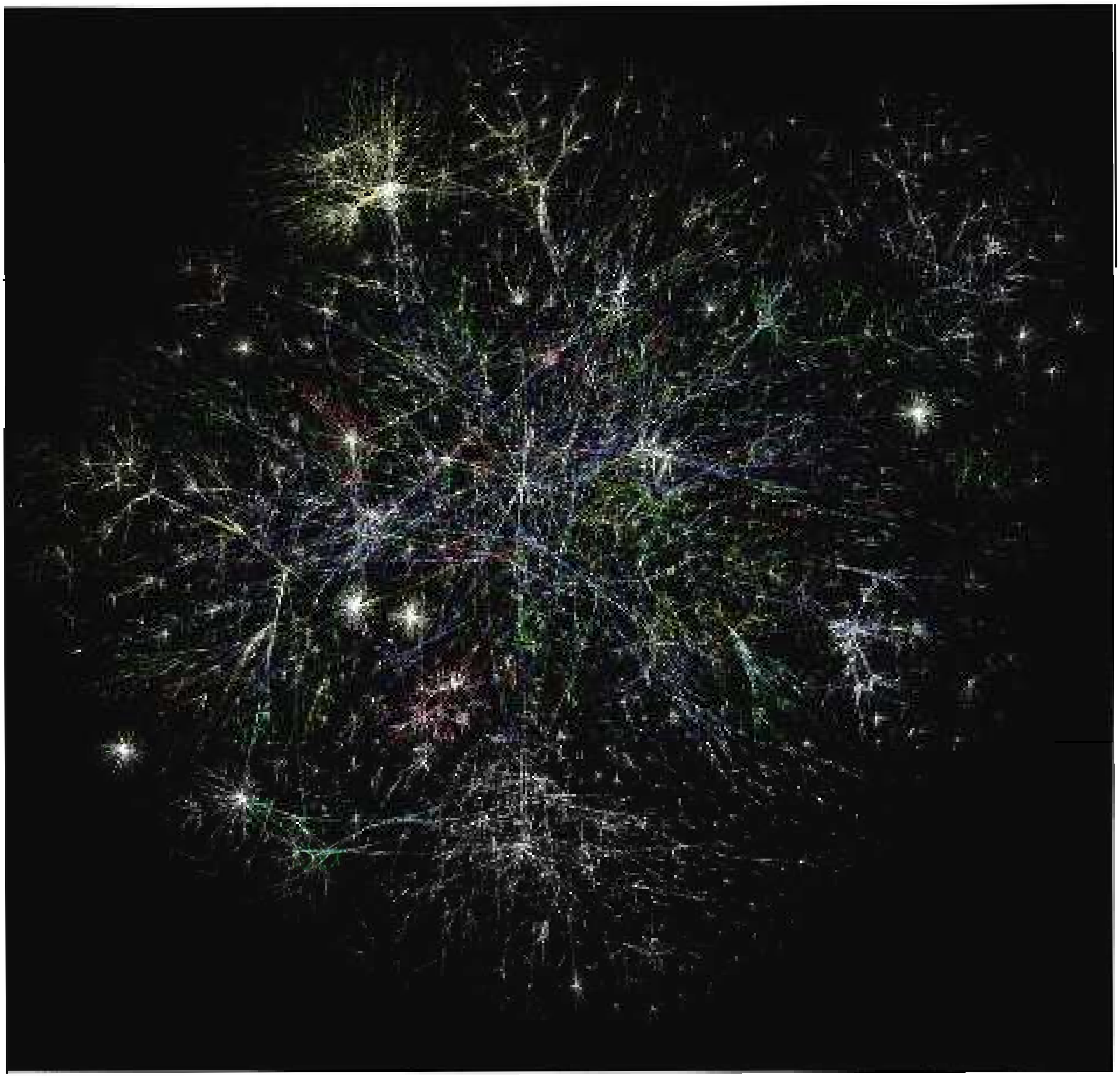
The information in this book is accurate to the best of the author's knowledge. However, neither the author nor the publisher can accept any responsibility for mistakes in identification or usage of species. People who eat mushrooms do so at their own risk. This material is intended for educational purposes only. It is advisable to seek the advice of a licensed professional health-care provider for any condition that may require medical attention.

Dedicated to Dusty



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FOREWORD

Mushrooms—ignored by many, reviled by some—may turn out to be important keys to both human health and planetary health. Their indispensable role in recycling organic matter, especially in forests, has long been known. But how many people realize that trees and other green plants could not grow and flourish without symbiotic associations with fungi—more, at least, with mycelium, the networks of fungal threads in soil that act as interfaces between plant roots and nutrients?

A mushroom is the reproductive structure of a fruiting body of mycelium. Mycelium runs through our world, achieving many other feats as well. It is a hidden and unappreciated strange life form that has not attracted the same scientific attention as microorganisms or plants or animals. Even conventional mycologists hardly recognize its larger implications and possibilities.

Paul Stamets has never been a conventional thinker. I have known him for 25 years, and during that time, I have been repeatedly impressed by his insights into the interdependence of human beings and nature, his enthusiasm for harnessing and directing "biological" energies toward human purposes, and his talent for thinking in novel and creative ways. He has always looked at mushrooms from unique perspectives and as a result has made remarkable discoveries about them.

When we first met, I was questioning why Western medicine had never looked to mushrooms as sources of new therapeutic agents, given their prominence in the traditional pharmacopoeias of China, Japan, and Korea. Paul took that question and ran with it, focusing on the natural competition that exists in soil between mycelium and bacteria. Fungi have evolved powerful defenses, a range of antibiotics that are effective against not only bacteria but also viruses and other infectious agents that cause disease in humans. One of the big ideas in this book is that fungi, especially fungi from old-growth forests, may be sources of new medicines that are active against a range of germs, including HIV/AIDS and the causative agents of smallpox and anthrax, potential bioterror threats.

Another of Paul's big ideas is that mycelium can be selected and trained to break down toxic waste, reducing it to harmless metabolites. He calls this strategy *mycoremediation* and has demonstrated its practicality in cleaning up oil spills. He suggests that certain mycelia may even be able to detoxify chemical warfare agents.

This is one facet of a larger strategy that Paul calls *mycorestoration*: the use of fungi to improve the health of the environment by filtering water, helping trees to grow in forests and plants to grow in gardens, and by controlling insect pests. The last possibility is especially impressive because it has the potential to [illegible] problems like toxic wastes and [illegible] by means that are completely nontoxic to human beings. Paul Stamets's [illegible] and [illegible] I look forward to seeing his ideas [illegible] put to use.

As a physician and practitioner of integrative medicine, I find this book exciting and important because it suggests new, nontoxic possibilities for solving serious problems that affect our health and the health of our environment. Paul Stamets has come up with those possibilities by observing an area of the natural world most of us have ignored. He has devoted his attention to mushrooms and mycelium and has used his unique intelligence and intuitive knowledge [illegible] decades of [illegible] I think you will find [illegible] and [illegible] the things in these pages.

Cortes Island, British Columbia
June 2005

ANDREW WEIL, MD

PREFACE

For 30 years I have engaged fungi, or perhaps they have engaged me, in a mission to promote the benefits of mushrooms. My previous books *Growing Gourmet and Medicinal Mushrooms* (2000), and *The Mushroom Cultivator*, coauthored with Jeff Chilton (1983), delved into the methods of cultivating mushrooms. This new book is designed to show readers how to grow mushrooms in gardens, yards, and woods for the purpose of reaping both personal and planetary rewards. As you will discover, mushrooms help us reconnect to nature in profound ways. Mushrooms, environmentally [illegible] trained, can be powerful allies in protecting the planet from the ecological injury we inflict.

More specifically, this book focuses on healing the planet using mycelial membranes, also known as mycelium, the fungal network of threadlike cells. It is a mycological manual for rescuing ecosystems, bringing mycelium to healing, a practice which I call "mycorestoration." The umbrella concept of mycorestoration includes the selective use of fungi for mycofiltration, mycoforestry, mycoremediation, and mycopesticides. Mycofiltration uses mycelium to catch and reduce silt and catch upstream contaminants. Mycoforestry uses mycelium and mushrooms to enhance forest health. Mycoremediation neutralizes toxins. Mycopesticides involve the use of fungi to help influence and control pest populations. This quartet of strategies can be used to improve soil health, support complex food chains, and increase sustainability in the biosphere.

This book is written for a readership as diverse as the fungal community. For readers devoted to recycling, organic cultivation, habitat restoration, or [illegible], I hope this book will be a useful [illegible] this revolutionary [illegible] part [illegible] remediation, ecological [illegible] physician, scientist, [illegible] is personally [illegible]. I hope this book enriches your life and that [illegible] your love of mushrooms [illegible]. And even if you have never walked through an old-growth forest, cultured fungi, [illegible] a fresh picked matsutake [illegible] over an open fire, or [illegible] mushroom-based medicines, I hope you will find this book — and my pragmatic [illegible] — informative and inspiring. I do not [illegible] that the planet's health actually depends on our [illegible] fungi. This book will show how you can [illegible] the world using mushrooms.

ACKNOWLEDGMENTS

Writing this book has been an adventure of a lifetime, for which I am indebted to many people. First, to my wife Dusty, I thank you for your love, companionship, humor, heart, and soul. Many thanks to Azureus and LaDena for all your help with my fieldwork and mycological projects. To my brother Bill, I thank you for [illegible] the challenges to my ideas that helped focus my vision. I am also grateful to Meghan Keefe, Karen O'Donnell Stein, Jeanne Stack, Laura Tenner, and Betsy Stromberg for their help in editorial comments and research in navigating [illegible] production of this book. To my family, especially my mother and late father, I am grateful that they supported me with their love and for nurturing my scientific curiosity. To Bill Weeks and to [illegible], thank you for placing your faith in me. To David Sumerlin, [illegible], [illegible], David Brigham, [illegible], [illegible], [illegible] Park, [illegible], Kevin [illegible], [illegible], George Osgood, Alex Winstead, and the other employees at Fungi Perfecti, thank you for helping in more ways than I can recount. To my mentors, Dr. Alexander Smith, Dr. Daniel Stuntz, and Dr. Michael Beug, who first encouraged me on this path, and to my [illegible] friend Dr. Andrew Weil, you hold special places in my heart.

Battelle Laboratories and their mycoremediation team, including Jack Word, Susan Thomas, Ann Drum, Meg Pinza, Pete Becker, and others are acknowledged for their contributions. Roger Gold and Cindy [illegible] of Texas A&M University [illegible] for their work on the [illegible] project. [illegible], [illegible], William [illegible], [illegible], [illegible], Tom [illegible], [illegible], John Norris, David Price, [illegible], [illegible], Phil Stern, and [illegible] also helped in their special ways.

I also want to thank my critics who have made me stronger, and [illegible] you will continue to [illegible] track the the sounds of mycologists, from [illegible] to [illegible] whose [illegible] experiences [illegible] the [illegible] that has become the [illegible] for the [illegible] revolution. [illegible], I am humbled by the [illegible] who have [illegible] spirit [illegible]. May future generations continue to build upon this foundation of knowledge to [illegible] the health of people and our planet.

Part I

THE MYCELIAL MIND

There are more species of fungi, by some estimates, in a single scoop of soil than there are species of plants and vertebrate animals in all of North America. And of these, fungi are the grand recyclers of our planet, the mycomagicians disassembling large organic molecules into simpler forms, which in turn nourish other members of the ecological community. Fungi are the interface organisms between life and death.

Look under any log lying on the ground and you will see fuzzy, cobweb-like growths called mycelium, a fine web of cells which, in one phase of its lifecycle, fruits mushrooms. This fine weave of cells courses through virtually all habitats—like mycelial tsunamis—unlocking nutrient sources stored in plants and other organisms, building soils. The activities of mycelium help heal and steer ecosystems on their evolutionary path, cycling nutrients through the food chain. As land masses and oceans have gone through successive generations of plants and animals that have lived, and died, fungi are keystone species that create ever-thickening layers of soil, which allow future plant and animal generations to flourish. Without fungi, all ecosystems would fail.

With each footstep on a lawn, field, or forest floor, we walk upon these sensitive cellular membranes. Fine, cobweb-like trails of mycelium channel nutrients from great distances to form fast-growing mushrooms. Mycelium, constantly on the move, can travel across landscapes up to several inches a day to weave a living network over the land. But mycelium benefits our environment far beyond simply producing mushrooms for our consumption.

Humans collaborate with these mycelial networks, using fungi, specifically mushrooms' mycelium, or spawn, for both short- and long-term benefits. Mushroom spawn helps us recycle garden waste, wood, and yard debris, thereby creating new ecological niches that heal habitats suffering from poor nutrition, stress, and toxic waste. In this sense, mushrooms emerge as environmental guardians in a time critical to our mutual evolutionary survival.

The human random genome is no longer the dominant force of human evolution. Our political, economic, and biotechnological policies now determine our future, for better or worse. Some futurists claim that half of the current species could disappear in the next hundred years if current trends continue. A Pentagon report issued in October 2003, *An Abrupt Climate Change Scenario and Its Implications for United States National Security* (Schwartz and Randall, 2003), hypothesizes that a more... the natural balance of our atmosphere and oceans could be radically destabilized as a result of pollution and global warming.

I wonder what would happen if there were a Chief Organizer of Organisms (COO), who determined which species gets removed. Would we be voted off the planet? The answer is pretty clear. When we irresponsibly exploit the Earth, disease, famine, and ecological collapse result. We face the possibility of being removed by the forces of nature as a virulent organism. But if we act as a responsible species, nature will not evict us. Our fungal friends can equip us with tools to act responsibly and repair our damaged environment, leading the way to habitat recovery. Understanding how to work with fungi—by companion planting fungal species with plant communities—is critical for our survival. The twenty-first century may be remembered as the Fungal Age, when these kinds of mycotechnologies play a prominent and increasing role in strengthening habitat health...

CHAPTER 1

Mycelium as Nature's Internet

I believe that mycelium is the neurological network of nature. Interlacing mosaics of mycelium infuse habitats with information-sharing membranes. These membranes are aware, react to change, and collectively have the long-term health of the host environment in mind. The mycelium stays in constant molecular communication with its environment, devising diverse enzymatic and chemical responses to complex challenges. These networks not only survive, but sometimes extend to thousands of acres in size, achieving the greatest mass of any individual organism on this planet. That mycelia can spread enormous cellular mats across thousands of acres is a testimonial to a successful and versatile evolutionary strategy.

The History of Fungal Networks

Animals are more closely related to fungi than to any other kingdom. More than 600 million years ago, we shared a common ancestry. Fungi evolved a means of externally digesting food by secreting acids and enzymes into their immediate environment and then absorbing nutrients using nets of cellular chains. Fungi marched onto land more than a billion years ago. Many fungi partnered with plants, which largely lacked these digestive means. Mycologists believe that this alliance allowed plants to inhabit land around 400 million years ago. Many millions of years later, the evolutionary branch of fungi led to the develop-

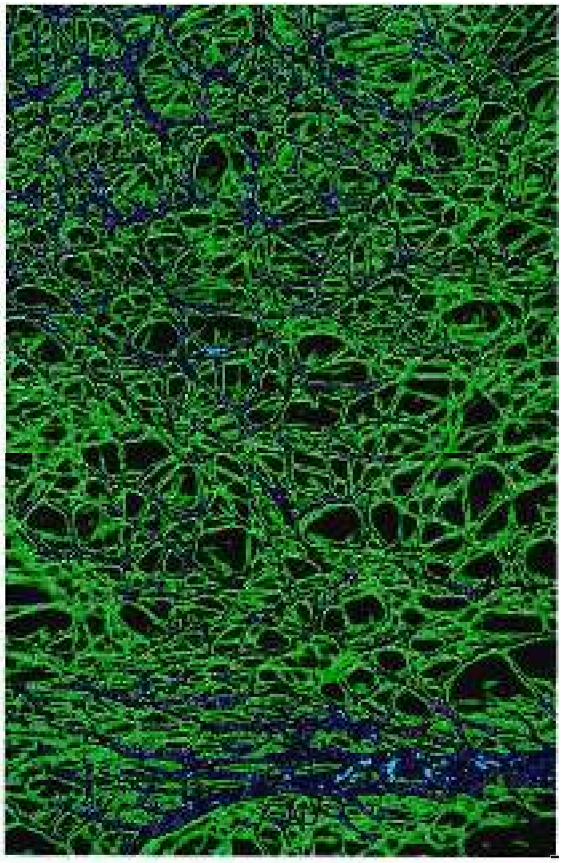
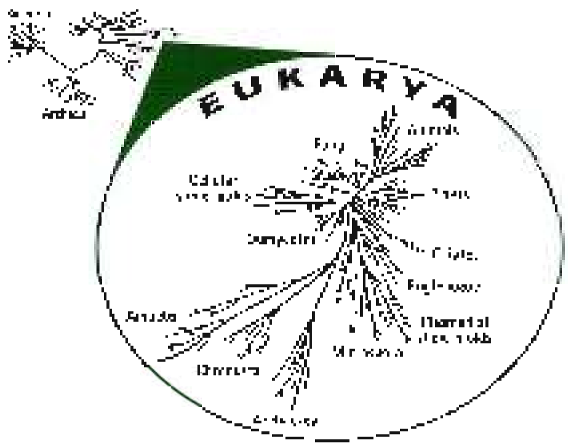


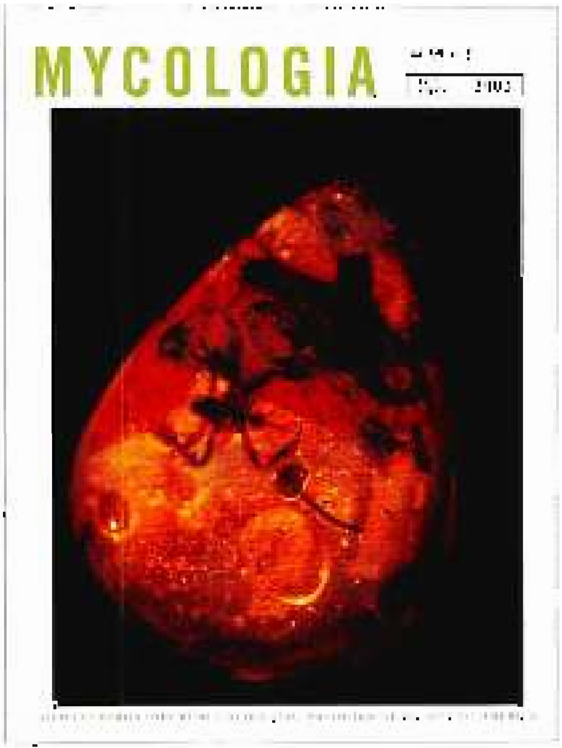
FIGURE 1

The mycelial network is composed of a membrane of interweaving, continuously branching cell chains only one cell wall thick.



➤ FIGURE A

Evolutionary Branches of Life. Animals have a more common ancestry with fungi than with any other kingdom, diverging about 650 million years ago. A new super-kingdom, Opisthokonta, has been erected to encompass the kingdoms Fungi and Animalia under one taxonomic canopy (Baldauf et al. 2000).



➤ FIGURE 2

The journal *Mycologia* featured this 15- to 20-million-year-old amber with a mushroom embedded, now called *Aureofungus yaniguaensis*, dating from Miocene times and collected in the Dominican Republic. The oldest mushrooms in amber are estimated at 90 to 94 million years old.

the rise of animals. The invention of fungi leading to animals evolved new environments by surrounding nutrition with cell membranes, essentially primitive stomachs. As species emerged from aquatic habitats, organisms adapted means to prevent moisture loss. In terrestrial creatures, skin composed of many layers of cells emerged as a barrier against infectious fungi. Fungi, on their evolutionary path, the mycelium retained a net-like form of interweaving chains of cells and went underground, forming a vast food web upon which life flourished.

About 250 million years ago, at the boundary of the Permian and Triassic periods, a catastrophe wiped out 90 percent of the Earth's species when, according to some scientists, a meteorite struck. Tidal waves, fires, toxic gases, and winds of more than a thousand miles per hour scourged the planet. The Earth darkened under a dust cloud of airborne debris, causing massive extinctions of plants and animals. Fungi inherited the Earth, surging to recycle the massive organic debris fields. The era of dinosaurs began and then ended 65 million years later when another meteorite hit, causing a second massive extinction. Once again, fungi surged and in turn, symbiotically partnered with plants for survival. The classic cap and stem mushrooms so common today are the descendants of varieties that predated this second catastrophic event. (The oldest gilled mushroom—encased in amber—is

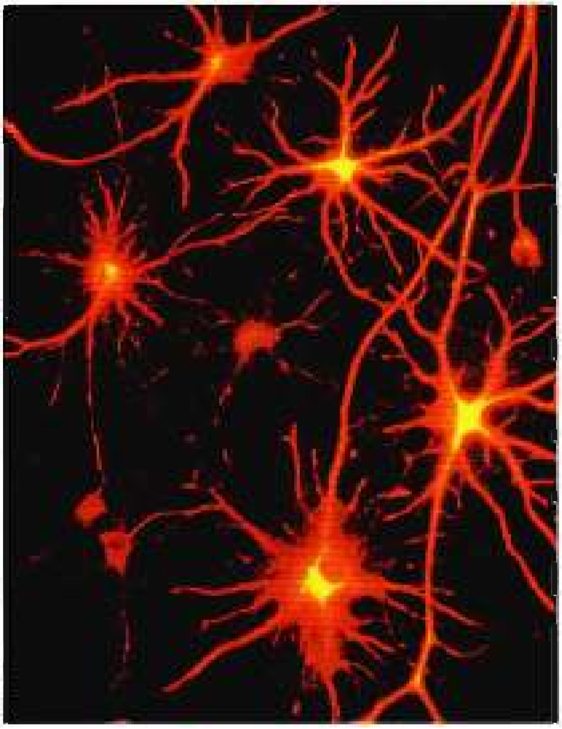


FIGURE 3

Micrograph of astrocytic neurons. Networking of neurons creates pathways for transmitting information. Mycelial nets share this same architecture.

collected in New Jersey, dates from Cretaceous times, 90 to 94 million years ago. Mushrooms evolved their basic forms well before the most distant mammalian ancestors of humans.) Mycelium steers the course of ecosystems by favoring the survival of species. Ultimately mycelium crafts an environment for its benefit, [illegible] ecosystems [illegible] its [illegible] [illegible].

Earth scientist James Lovelock, together with Lynn Margulis, came up with the Gaia hypothesis, which postulated that the Earth's biosphere intelligently selects its course to sustain and breed new life. I see mycelium as the living network that manifests this natural intelligence imagined by Gaia theorists. The mycelium is an exposed sentient membrane, aware and responsive to changes in its environment. As hikers, deer, or insects walk across these sensitive filamentous nets, they leave impressions, and mycelia sense and respond to these movements. A complex and resilient infrastructure for sharing information, mycelium can adapt and evolve through the ever-changing forces of

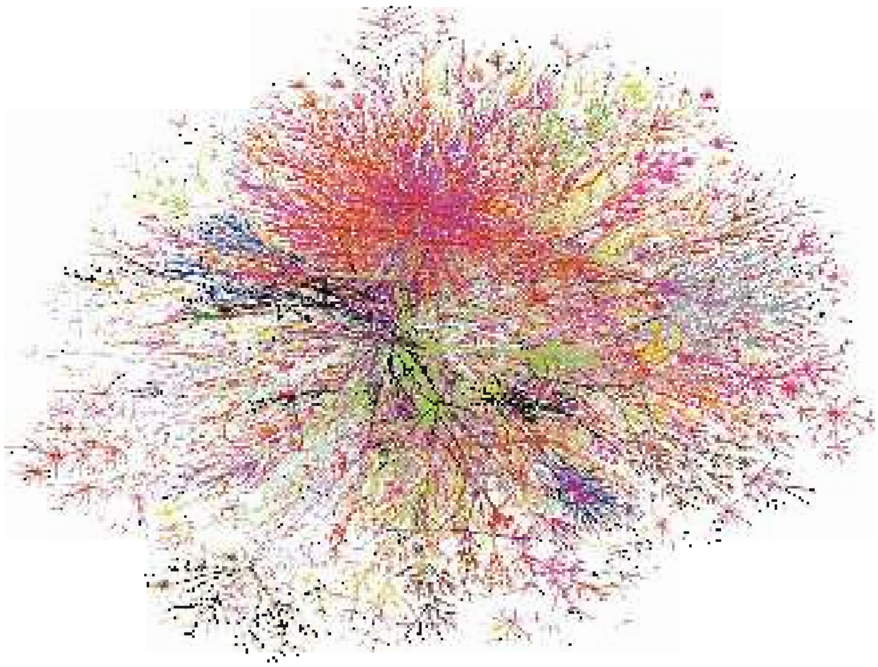
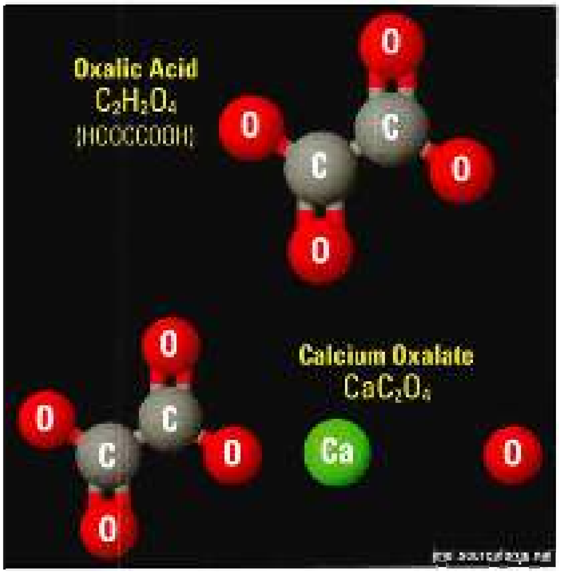


FIGURE 4

A diagram of the overlapping information-sharing systems that comprise the Internet.



FIGURES B AND C

Oxalic acid and calcium oxalate. Oxalic acid crystals are formed by the mycelia of many fungi. Oxalic acid mineralizes rock by combining with calcium and many other minerals to form oxalates, in this case calcium oxalate. Calcium oxalate sequesters two carbon dioxide molecules. Collectively, mushroom mycelia unfold into complex food webs, crumbling rocks as they grow, creating dynamic soils that support diverse populations of organisms. Below: Scanning electron micrograph of calcium oxalate crystals forming upon mycelium.

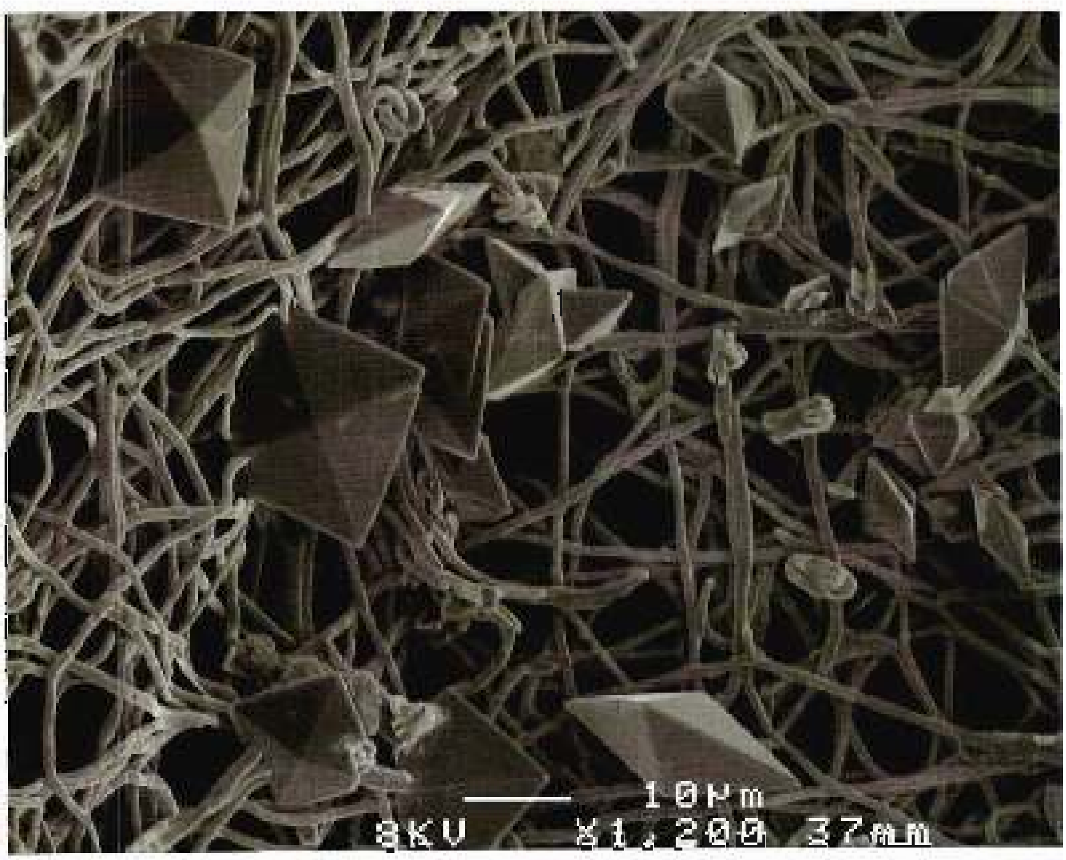


FIGURE D

Prototaxites was the name given to this fossil— [illegible] approximately 420 million years [illegible] existence at the end of the late Silurian and through the beginning of the Devonian periods. Found in Canada and Saudi Arabia, this organism was widespread across the [illegible]. First described in 1859, this fossil remained a mystery until C. Kevin Boyce and others showed that it was a giant fungus in 2007.

FIGURE E

Artist's depiction of Prototaxites, which was the tallest known organism on land [illegible] reaching [illegible]. The tallest plants that lived next to Prototaxites were less than 1 meter high.

nature. I especially feel that [illegible] entering a forest [illegible], I believe [illegible] interlacing mycelial [illegible]. These sensitive mycelial membranes act as a collective fungal consciousness. As mycelia are always [illegible], they [illegible], imparting [illegible] to the [illegible], and connecting ecosystems and their species with [illegible]. Like a matrix, [illegible], the mycelium is in constant dialogue with its environment, reacting to and governing the flow of essential nutrients cycling through the food chain.

I believe that the mycelium operates at a level of complexity that exceeds the computational powers of our most advanced supercomputers. I see the mycelium as the Earth's natural Internet, a consciousness with which we might be able to communicate. Through cross-species interfacing, we may one day exchange information with these sentient cellular networks. Because these [illegible] networks are [illegible] upon them, [illegible] footsteps [illegible] falling [illegible], they could [illegible] enormous amounts of data regarding the movements of all

FIGURE 5

A slime mold, *Physarum polycephalum*, chooses the shortest route between 2 food sources in a maze, disregarding dead ends [illegible]. Toshiyuki Nakagaki proposes that this represents a form of cellular intelligence.

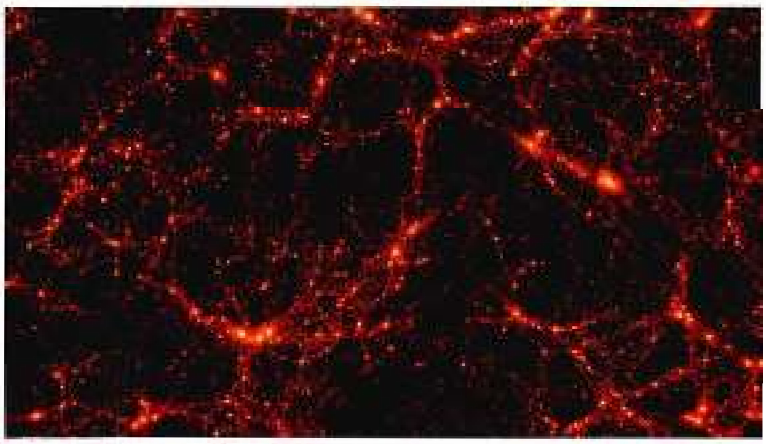


FIGURE 6

Computer model of the early universe [illegible] dark matter [illegible] filamental archetype.

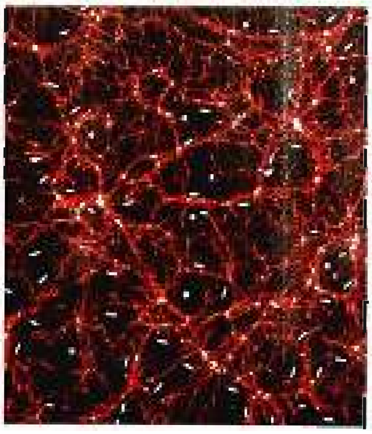


FIGURE 7

Computer model of dark matter [illegible] universe. In a conjunct of string theory, more than 90 percent of the mass of the universe is believed to be composed of these [illegible] threads. Note the galaxies interspersed throughout the mycelium-like network.

FIGURE 8

Cultures of a yet-to-be-named Californian *Psilocybe* mushroom swirl like a cyclone as they grow outward. The rate of growth increases with time.

FIGURE 9

Several mosaic mats of the root-rot *Armillaria* mushroom spiral outward, killing a forest in Montana. Once the trees die, they become highly flammable. (See also figure 33 for a large patch of *Armillaria*, the largest organism in the world.)

organisms through the landscape. A new bioinformatic science could be born, dedicated to programming mycoecological networks to monitor and respond to threats to ecosystems. Mycelial webs could be used as information platforms for surveying the ecosystems.

The idea that a cellular organism can demonstrate intelligence might seem radical. Enter the work by researchers like Toshiyuki Nakagaki (2000). He placed a maze over a petri dish filled with the nutrient agar and then placed nutritious oat flakes at the entrance and exit. He then inoculated the entrance with a culture of the slime mold *Physarum polycephalum* under sterile conditions. As it grew through the maze it consistently chose the shortest route to the oat flakes at the end, rejecting dead ends and multiple exits, demonstrating a form of cellular intelligence according to Nakagaki and his fellow researchers. If this is true, then the neural nets of mushrooms and mycelia may be deeply intelligent.

A few recent finds support the novel perspective that fungi can be intelligent, or may have potential as such. Fungi—perhaps being programmed to reflect environmental data as suggested above, or to communicate with silicon chips in a computer interface—... Envisioning fungi as instruments in mycocomputers, [illegible] (2004) and his fellow researchers at Northwestern University have manipulated networks of *Aspergillus niger* to organize gold into DNA, in effect creating mycelial conductors of electrical potentials. NASA reports that microbiologists at the University of Tennessee, led by Gary Sayler, have developed a rugged biological computer chip housing bacteria that glow upon sensing pollutants, from heavy metals to PCBs (Miller 2004). Such innovations hint at new biotechnologies on the near horizon. Working together, fungal networks and environmentally responsive bacteria could provide real-time data around pH, chemical runs, and toxic waste, and even measure biological populations.

Fungi in Outer Space?

Fungi may not be unique to Earth. Scientists theorize that life is spread throughout the cosmos, and that it is likely to exist wherever water is found in a liquid state. Recently, scientists detected a distant planet 5,600 light years away, which formed 13 billion years ago, old enough that life could have evolved there and become extinct several times over (Savage et al. 2003). [illegible] seeds for life to evolve on Earth? Thus far, 40 planets outside our solar system have been discovered, and more are being discovered every few months. Astrobiologists believe that the precursors of DNA, nucleic acids, are forming throughout the cosmos as an inevitable consequence of matter as it organizes, and I have little doubt that we will eventually survey planets for microscopical communities. The fact that NASA has established the Astrobiology Institute and that Cambridge University Press has established *The International Journal of Astrobiology* strongly support for the theory that life seems to be created and is widely distributed throughout the galaxies. I predict an interplanetary *Journal of Astromycology* will emerge as fungi are discovered on other planets. It is possible that protogerm plasm could travel throughout the galactic expanses riding upon comets or carried by stellar winds. This form of interstellar protobiological migration, known as panspermia, does not sound as far-fetched today as it did when first proposed by Sir Fred Hoyle and Chandra Wickramasinghe in the early 1970s. NASA considered the possibility of using fungi for interplanetary colonization. Now that we have landed rovers on Mars, NASA takes seriously the unknown consequences that our microbes will have on seeding other planets. Spores have no borders.

The Mycelial Archetype

Nature tends to build upon its successes. The mycelial archetype can be seen throughout the universe: in the patterns of hurricanes, dark matter, and the Internet. The similarity in form between these may not be merely a coincidence. Biological systems are constrained by the laws of physics, and it may be that mycelium expands at the rate of momentum of nature, just like stars take advantage of the rules. The architecture of mycelium resembles patterns predicted in string theory, and astrophysicists theorize that the most energy-conserving form in the universe will be recognized as threads of matter/energy. The arrangement of these strings resembles the architecture of mycelium.

FIGURE 10

Hurricane Isabel approached the North American coast in October 2003.

FIGURE 11

Spiral galaxies conform to the same archetypal pattern as hurricanes and mycelia.

When the Internet was designed, its [illegible] structure maximized the pooling of data and [illegible] data power while minimizing critical points upon which the system is dependent. I believe that the structure of the Internet is simply an archetypal form, the inevitable consequence of a previously proven evolutionary model, which is also seen in the human brain. Diagrams of computer networks bear resemblance to both mycelium and neurological maps in the human mind (see figures 8 and 11). Our understanding of information networks in their many forms will lead to innovations [illegible] computational power (Bebber et al. 2007).

Mycelium in the Web of Life

As an evolutionary strategy, mycelial architecture is amazing: one cell wall thick, in direct contact with myriad microorganisms, and yet so pervasive that a single cubic inch of topsoil contains enough fungal cells to stretch more than 8 miles if placed end to end. I estimate that every footstep I take impacts more than 300 miles of mycelium. These fungal fabrics run through the top few inches of virtually all landmasses that sustain life, sharing the soil with legions of other organisms. If you were a tiny organism in a forest's soil, you would be enmeshed in a carnival of activity, with mycelium constantly moving through spontaneous landscapes like giant brownies, through dancing bacteria and swimming protozoa, with nematodes sashaying like whales through a microcosmic sea of life.

Worldwide, fungi decompose and recycle plant debris, filter microbes and sediments from water, and restore soil. In the end, life-sustaining soil is created from debris, particularly dead wood. We are now entering a time when mycofilters of select mushroom species can be constructed to destroy toxic waste and prevent disease, such as infection from coliform or staph bacteria and protozoa and [illegible] disease-carrying organisms. In the near future we can orchestrate selected mushroom species to manage species succession. While mycelium nourishes plants, mushrooms then serve as a nutrient niche for worms, insects, mammals, bacteria, and other parasitic fungi. I believe that the occurrence and decomposition of a mushroom predetermines the nutritional and temporal basis [illegible] downstream populations [illegible].

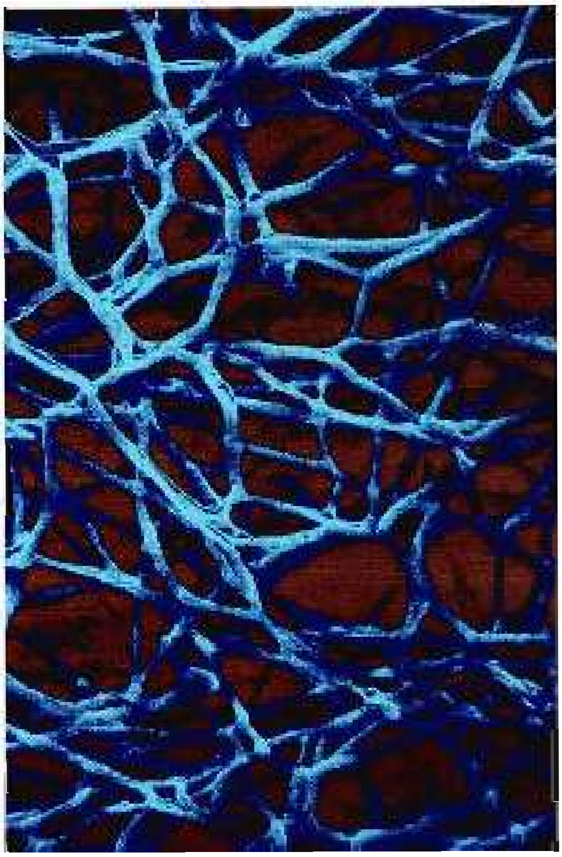


FIGURE 12

Close-up of mycelium.

Whenever a catastrophe creates a field of debris—whether from downed trees or an oil spill—many fungi respond with waves of mycelium. This adaptive ability reflects the deep-rooted ancestry and diversity of fungi, resulting in the evolution of a whole kingdom estimated with between 1 and 2 million species. Fungi outnumber plants at a ratio of at least 6 to 1. About 10 percent of fungi are what we of nine microns (Hawksworth 2001), and only about 10 percent of the estimated species have been identified, meaning that our taxonomic knowledge of mushrooms is exceeded by our ignorance by at least one order of magnitude. The surprising diversity of fungi speaks to the essential role needed for a healthy environment. What has been become increasingly clear to mycologists is that assessing the health of the environment is directly related to our understanding of the roles of its complex fungal populations. Our bodies and our environments are habitats with immune systems; fungi are a common bridge between the two.

All habitats depend directly on these fungal allies, without which the ecological system of the Earth would soon collapse. Mycelial networks hold soils together and aerate them. Fungal enzymes, acids, and antibiotics dramatically affect the evolution and structure of soils (see page 13). In the wake of catastrophes, fungal diversity helps restore devastated habitats. Evolutionary trends generally lead to increased biodiversity. However, due to human activities we are losing many species before we can even identify them. In effect, as we lose species, we are experiencing devolution—turning back the clock on biodiversity, which is a slippery slope toward massive ecological collapse. The interconnectedness of life is an obvious truth that we ignore at our peril.

In the 1960s, the concept of "better living through chemistry" became the ideal as a variety of toxic pesticides, fungicides, and petrochemicals were born in the laboratory. When these chemicals were released into nature, they often had a dramatic and initially desirable effect on their targets. However, events in the past few decades have shown that many of these inventions were in fact at the same time exacting a heavy toll on the biosphere. We have now learned that we must tread softly on the web of life and deal with it with more benevolence.

Toxic fungicides, like modified triazoles, once touted not only harm targeted species but also nontargeted organisms and their food chains and weaken the ozone layer. Because resistance develops, a new fungicide is needed for a temporary solution until tolerance is achieved. When the natural beneficial fungi have been repressed, the perceived need for chemical fertilizers increases, creating a cycle of chemical dependency, ultimately eroding sustainability. However, we can create mycologically sustainable environments by introducing plants and fungi (mycorrhizal and endophytic) in conjunction with mulching with saprophytic mushroom mycelium. The results of these fungal activities include healthy soil, biodynamic communities, and endless cycles of renewal. With every year, soil depth increases and the capacity for biodiversity is enhanced.

Living in harmony with our natural environment is key to our health as individuals and as a species. We are an extension of the environment that has given us birth. Wantonly destroying our life-support ecosystems is tantamount to suicide. By acting fungally, we can reduce the environmental damage inflicted by humans by accelerating organic decomposition of the massive fields of debris we create—through everything from clearcutting forests to constructing cities. Our relatively sudden rise as a destructive species is surpassing the fungal recycling systems of nature. The cascade of toxins and debris generated by humans destabilizes natural nutrient cycles, causing crop failure, global warming, climate change, and, in a worst-case scenario, quickening the march toward the extermination of our own kind. As ecological disruptors, humans challenge the immune systems of our environment beyond their limits. The rule of nature is that when a species exceeds the carrying capacity of its host environment, its food chains collapse and diseases emerge to devastate the population of the threatening organism. I believe we can come into balance with nature using mycelium to regulate the flow of nutrients. The use of mycological medicine is paramount. Now is the time to ensure the future of our planet and our species by partnering, or farming, with mycelium.

CHAPTER 2

The Mushroom Life Cycle

For [illegible] feeling [illegible], a better understanding of the mushroom life cycle is helpful. Although we notice mushrooms when they pop up, their [illegible] is the [illegible] of cellular events largely hidden from view until the inquisitive mycophile digs deeper. Although mycologists have a basic understanding of the mushroom life cycle, we are clueless how mushroom species interact with [illegible] other organisms coexisting in the same habitat. With each [illegible] revealed, the hazy [illegible] of ecology expands, and our knowledge [illegible] inches forward. What is so exciting about mycology is that the domain of undiscovered knowledge lying before us is more vast than our minds can imagine.

Mushrooms reproduce through [illegible] microscopic spores, visible [illegible] when they [illegible]. When the moisture, temperature, and nutrients are right, spores freed from a mushroom [illegible] germinate into threads of cells called hyphae. As each hypha grows and branches, it forms connections with other hyphae from compatible spores to create a mycelial mat, which [illegible] gathering nutrients and moisture. From [illegible] aggregate to form a primordium [illegible] called [illegible]. Under optimal conditions, the transformation from spore to [illegible] mushroom can take just a few days.

Mushrooms can be divided into 3 basic categories depending upon how they form: predators, [illegible]

FIGURE 13

Depiction of the mushroom life cycle.

FIGURE 14

Scanning electron micrograph of a primordium forming from a [illegible] sample content of Mycelium Running: How Mushrooms Can Help Save the World

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