MYCELIUM RUNNING

MYCELIUM RUNNING

How Mushrooms Can Help Save the World

PAUL STAMETS

TEN SPEED PRESS
Berkeley

Library of Congress Cataloging-in-Publication Data
Stamets, Paul.
Mycelium running : how mushrooms can help save the world / Paul Stamets.
p. cm.
Includes bibliographical references and index.
1. Mycelium. 2. Mushroom culture. 3. Fungi–Ecology. I. Title.
QK601.S73 2005
579.5'163—dc22 2005015968

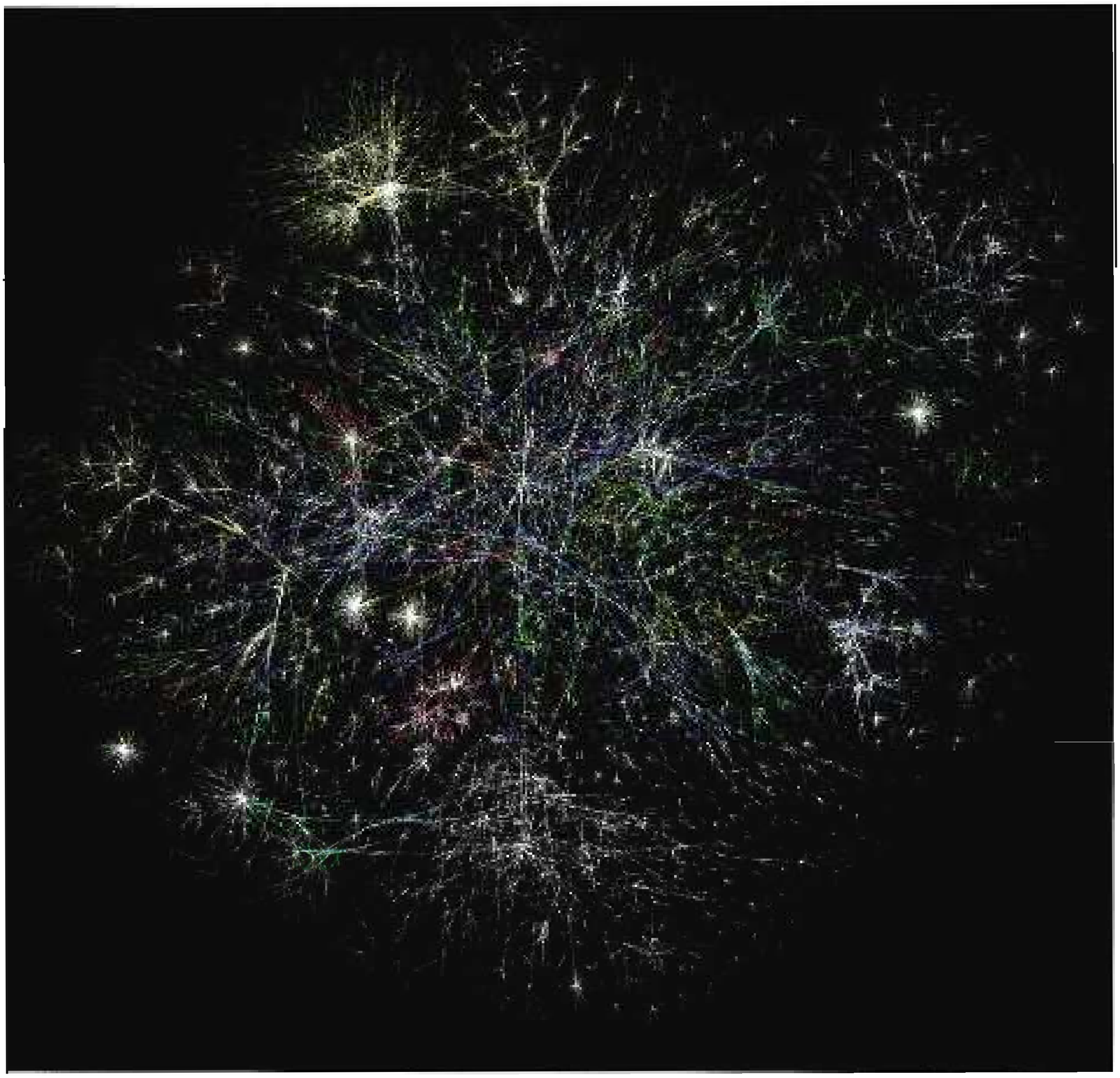
ISBN 978-1-58008-579-3
Printed in China through Colorcraft Ltd., Hong Kong

Cover design by Betsy Stromberg and Andrew Benzie
Text design by Betsy Stromberg

15 14 13 12 11 10 9 8 7

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 inappropriate use of mushrooms; people who eat mushrooms do so at their own risk. This material is intended for educational purposes only; it is not a substitute for seeking the advice of a licensed professional health care provider for any condition that may require medical attention.

Dedicated to Dusty



CONTENTS

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 mushrooms, 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 or fruiting body of mycelium. Mycelium runs through our world, achieving many other feats as well, and it is hidden and unexpected, a strange life form that has not attracted the same scientific attention as microorganisms or plants or animals. Even conventional mycologists rarely 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 drugs, although they are given such prominence in the traditional pharmacopoeias of China, Japan, and Korea. Paul took the question and ran with it, focusing on the natural competition that exists in soil between mycelium and bacteria. Fungi have evolved powerful defense systems, 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 effective 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 our mushroom allies 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 big possibility is especially impressive because it has the potential to control pests like termites and fire ants by means that are completely nontoxic to human beings. Paul Stamets took out a broad patent on it this year, and I look forward to seeing the invention put to use.

As a physician and practitioner of integrative medicine, I find this book exciting and inspirational 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 these possibilities by observing an area of the natural world most of us have ignored. He has directed his attention to mushrooms and mycelium and has used his unique intelligence and intuition to make discoveries of great practical import. I think you will find it hard not to share the enthusiasm and passion he brings to 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), delve 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 can help us reconnect to nature in profound ways. Mushrooms, environmental and medicinal, 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 the healing of habitats in what 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 denatures toxic wastes. 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 diverse 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 alternative ecology, I hope this book will be a useful, if not revolutionary, resource. [illegible] remediation, ecoforestry, sustainable agriculture, physician, scientist, student, or anyone who is passionately concerned, I hope this book carries over my life and that you will pass on the love of mushrooms to future generations. And even if you have never walked through an old-growth forest, cultured fungi, or [illegible] a fresh-picked matsutake grilled over an open fire, or eaten a mushroom-based medicine, I hope you will find this book—and my pragmatic [illegible]—informative and inspiring. I contend that the planet's health actually depends on our reaction to fungi. This book will show how you can help save 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 [illegible]. Many thanks to Azureus and La Dena for all your help with my field work and fungal projects. To my brother Bill, I thank you for your [illegible] challenges early on that helped focus my vision. I am also grateful to Meghan Keefe, Karen O'Donnell Stein, Jennifer Stanley, Laura Lerner, and Betsy Stromberg for their helpful editorial comments and research [illegible] that greatly aided the production of this book. To my parents, especially my mother and late father, I am grateful. Her love has supported me with [illegible] and for nurturing my scientific curiosity. To Bill Webb and to Ann Dech, thank you for placing your faith in me. To David Sumerlin, Steve Chadwick, Jimmy Coyle, David Brigham, Andrew Lenzer, Marie Maverick, Dennis Park, Nanda Rita, Kevin Schoenecker, Bulmaro Soto, 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 old friend Dr. Andrew Weil, you hold special places in my heart.

[illegible] and their [illegible] dedicated team, including Jack Wells, Susan Thomas, Ann Dillon, Meg Zimmer, Pete Benson, and others are acknowledged for their contributions. Roger Gold and Cindy Glenn of Texas A&M University are thanked for their work on the [illegible]. Dave Arora, Norm Bradley, William Hewitt, Orson K. Miller, [illegible], Tom Nealon, Bill Nicholson, John Norris, David Price, Ethan Schiller, Nina Stevens, Phil Stern, and Solomon Wasser 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] [illegible] the ranks of mycologists, from [illegible] to [illegible], whose [illegible] experience [illegible] the [illegible] that has become the [illegible] for the [illegible] evolution [illegible]. Last, I am humbled by the psilocybes who have [illegible] spirit [illegible]. May future generations continue to profit from this foundation of knowledge to [illegible] the health of people and our planet.

Part I

THE MYCELIAL MIND

There are more species of fungi [illegible] one [illegible] 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 life cycle, fruits mushrooms. This fine web of cells courses through virtually all habitats—like myceliated mantles—unlocking nutrient sources stored in plants and other organisms, building soils. The activities of mycelium help heal and steer ecosystems on their evolutionary paths, cycling nutrients through the food chain. As ecosystems mature [illegible] generations, forms of plants and animals are born, live, and die. 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 omnisentient cellular membranes. Fine cobweb-like tracks 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 cellular networks, using fungi, specifically gourmet mushroom species, for both short- and long-term benefits. Mushroom spawn helps us recycle garden waste, wood, and sawdust, thereby creating mycological landscapes that restore 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 renewal.

The forces of random [illegible] are no longer the dominant force of human evolution. Our political, economic, and biotechnological policies now determine our future, for better or worse. Some forecasters 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 [illegible] more [illegible] and [illegible] human [illegible] become radically destabilized as a result of pollution and global warming.

I wonder what would happen if there were a United Organization of Organisms (UOO), [illegible] where each species gets one vote. 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 rejected by the biosphere as a virulent organism. But if we act as a responsible species, nature will not evict us. Our fungal friends are equipping us with tools to act responsibly and repair our damaged environment, leading the way to habitat recovery. Knowing how to work with fungi—by companion pairing 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 testimony 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 networks of cell chains. Fungi marched onto land more than a billion years ago. Many fungi partnered with plants, which largely lacked these digestive tissues. 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-

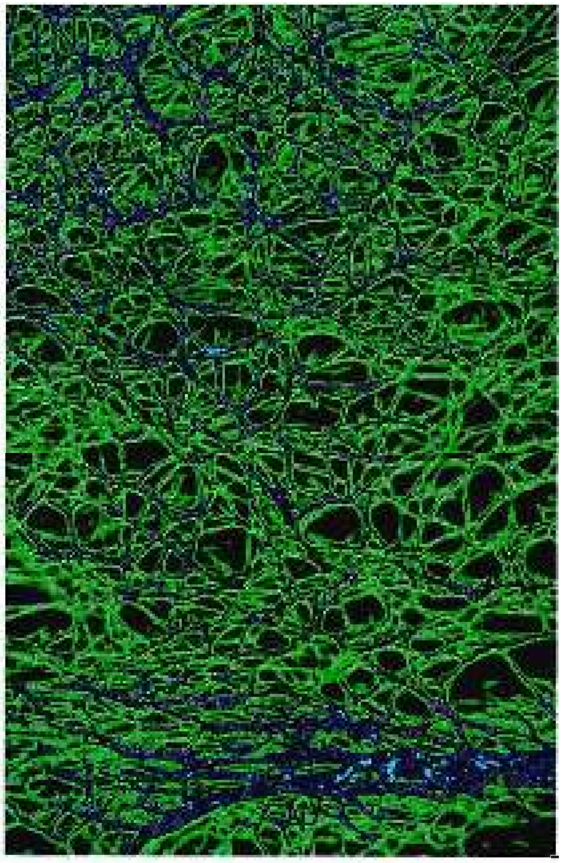
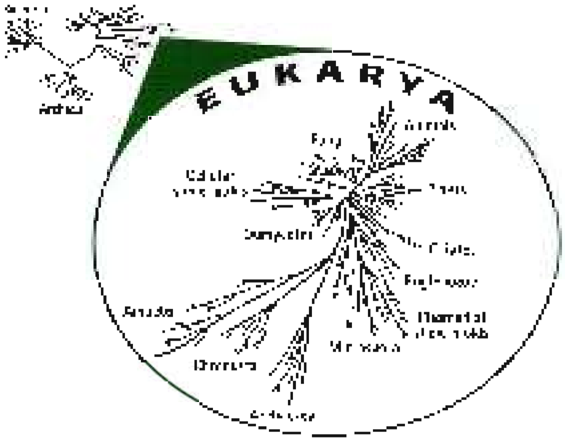


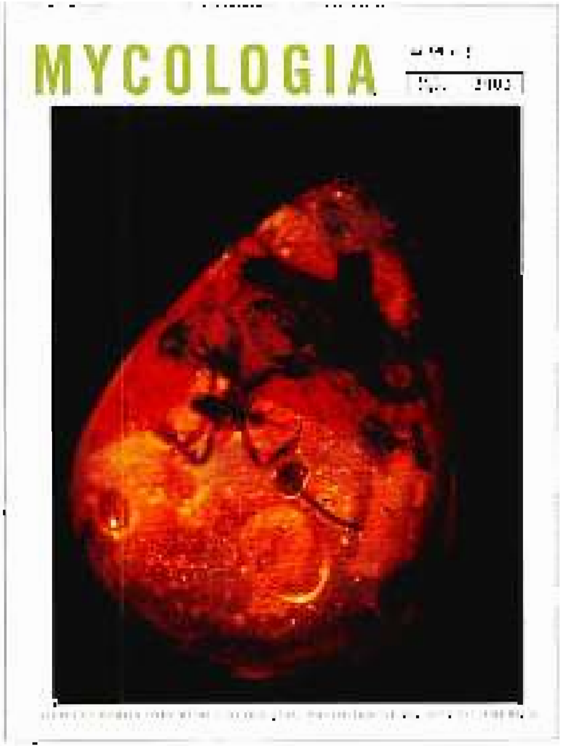
FIGURE 1

The mycelial network is composed of a membrane one cell wall thick, weaving, continuously branching cell chains [illegible]



➤ 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 this one taxonomic canopy (Baldauf et al. 2000).



➤ FIGURE 2

The journal Mycologia featured this 15 by 20 mm piece of 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 from environments by surrounding nutrition and cell tubes, 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 diseases. Taking another 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. Dust, rocks, trees, ash, gases, and vapors for more than a thousand years circled around the planet. The Earth darkened under a thick 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 those 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 known mushroom—encased in amber—came

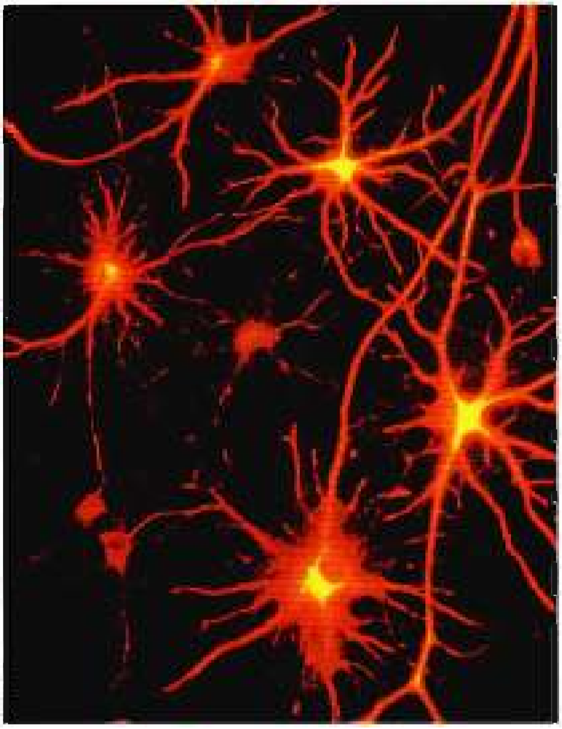


FIGURE 3

Micrograph of astrocyte brain cells. Networking of neurons creates pathways for distributing information. Mycelial nets share this same architecture.

collected in New Jersey, dates from Cretaceous times, 92 to 94 million years ago. Mushrooms evolved their basic forms well before the most distant mammal ancestors of humans.) Mycelium steers the course of ecosystems by forming mosaics of species, ultimately transforming organic and mineral environment for its benefit, growing ecosystems that suit its best climate.

Researcher James Lovelock, together with Lynn Margulis, came up with the Gaia hypothesis, which postulated that the Earth's biosphere intelligently orchestrates to sustain and breed new life. I see mycelium as the living network that manifests the 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 mats, they leave impressions, and mycelia sense and respond to these movements. A complex and tenacious infrastructure for sharing information, mycelium can adapt and evolve through the ever-changing forces of

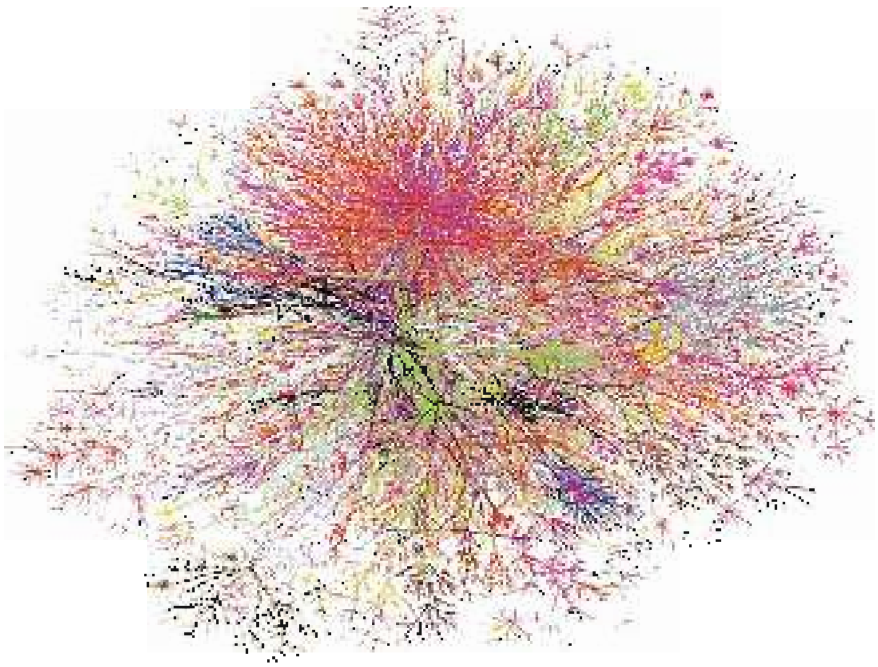
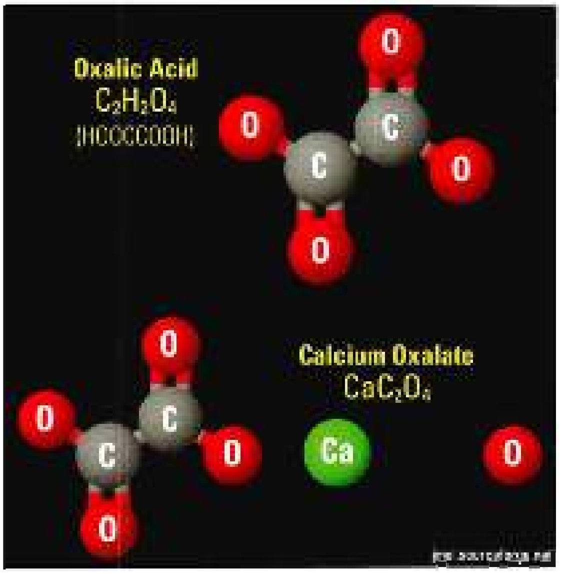


FIGURE 4

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.

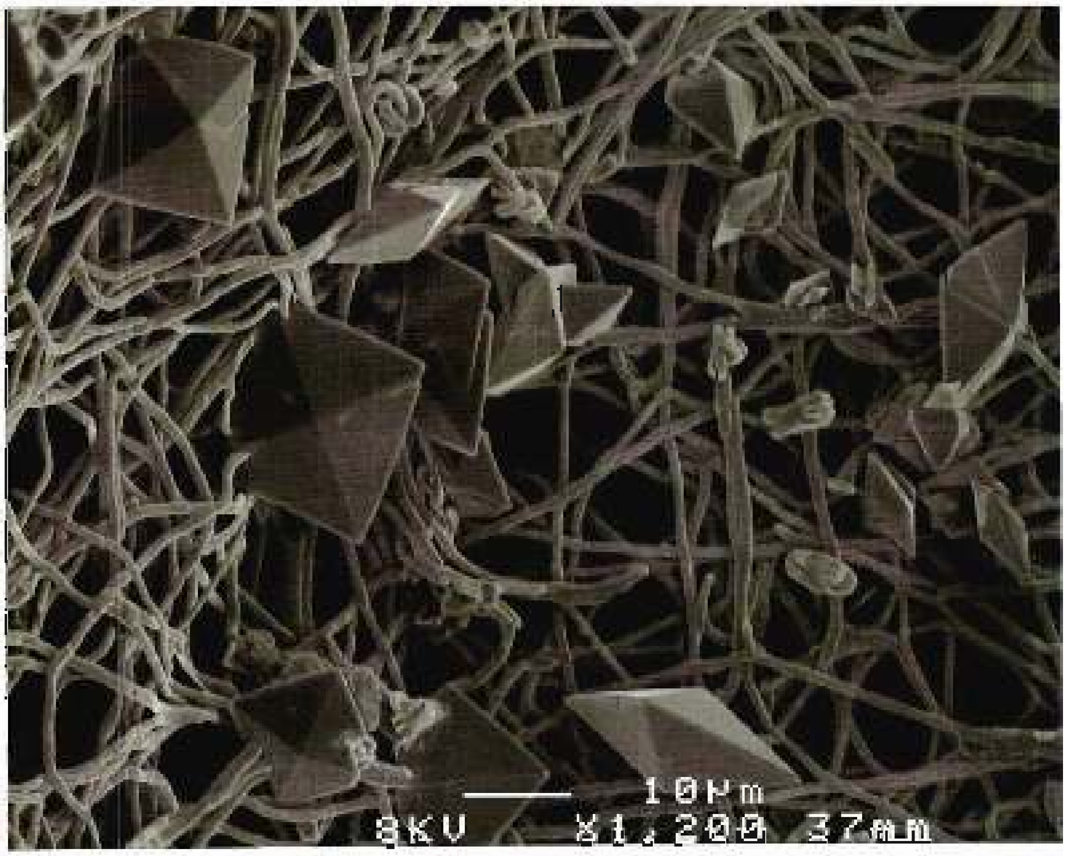


FIGURE D

Prototaxites was the name given to this fossil—measuring [illegible] 420 million years [illegible] existent 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]. [illegible] first described in 1856, this fossil remained a mystery until C. Kevin Boyce and others discovered that it was a giant fungus in 2007.

FIGURE E

Artist's depiction of Prototaxites, which was the tallest known organism on land [illegible] its time, [illegible] The tallest plants [illegible] Prototaxites, were less than a meter high.

[illegible]ture. These [illegible] entering a forest [illegible]. These sensitive mycelial membranes act as a collective fungal consciousness. As mycelia [illegible], [illegible] and connecting ecosystems and [illegible] species [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] neurological nets sense any impression upon them, from footsteps to falling tree branches, they could relay 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.

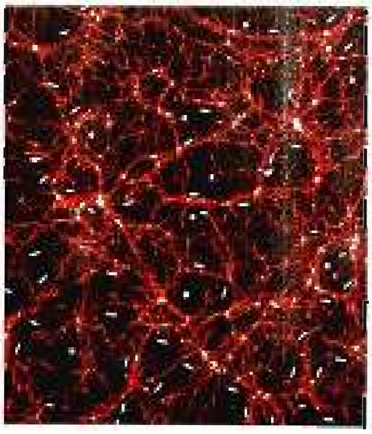


FIGURE 6

Computer model of the early universe [illegible] the universal archetype.

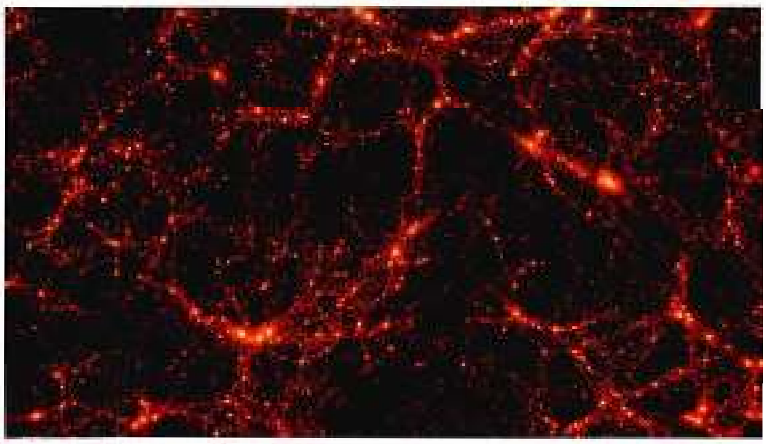


FIGURE 7

Computer model of dark matter in the 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 threads.

▲ FIGURE 8

Cultures of the 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 mycelial mats of the root-rot *Armillaria* mushroom spiral outward, killing a forest in Montana. Once these trees die, they become highly flammable. (See also figure 20 for a larger patch of *Armillaria*, the largest organism in the world.)

organisms through the landscape. A new bioneering science could be born, dedicated to programming mycotechnological networks to monitor and respond to threats to our ecosystems. Mycelial webs could be used as information platforms for monitoring entire ecosystems.

The idea that a cellular organism can demonstrate intelligence might seem radical. But consider the work by researchers like Toshiyuki Nakagaki (2000). He raised a maze over a petri dish filled with the nutrient agar and introduced 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 ample 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 findings support the novel perspective that fungi and bacteria may have potential as computers, perhaps being programmed to reflect environmental data as suggested above, or to communicate with silicon chips in a computer interface. Envisioning fungi as instrumental in mycocomputers, Gorman (2003) 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 frontier biotechnologies on the near horizon. Working together, fungal networks and environmentally responsive bacteria could provide real-time data about pH, detect nutrients 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). (Earth is 4.5 billion seeds for life to evolve on Earth? Thus far, 100 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 mycological communities. The fact that NASA has established the Astrobiology Institute and that Cambridge University Press has established *The International Journal of Astrobiology* strongly support the theory that life seems [illegible] and is likely 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 protogenic spores could travel throughout the galactic expanses riding on 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. [illegible] 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 influenced by the laws of physics, and it may be that mycelium expands at the rate of momentum of nature, just like [illegible] take advantage of the rules. The architecture of mycelium resembles patterns predicted in string theory, as do astrophysicists' theories that the most energy-conserving forms in the universe will be organized as threads of matter/energy. The arrangement of these strings resembles the architecture of mycelium.

FIGURE 10

Hurricane Isabel [illegible] toward the North Atlantic [illegible] 2003.

FIGURE 11

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

When the Internet was designed, its evolving structure maximized the pooling of data and eventually total 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 arrays in the human mind (compare figures 8 and 11). Our understanding of information networks in their many forms will lead to an exponential leap in human 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 forest soil 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 our eyes could see through a forest's soil, we would be entranced in a carnival of activity, with mycelium constantly moving through spontaneous landscapes like visible waves, through dancing bacteria and swimming protozoa with nematodes wriggling 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 viruses carried by disease-carrying organisms. In the near future we can orchestrate selected mushroom species to manage species succession. While mycelium nourishes plants,

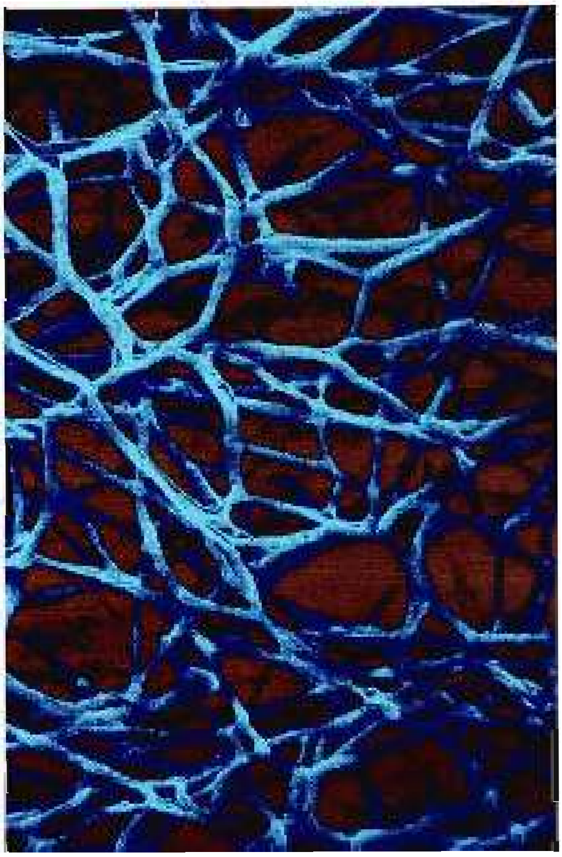


FIGURE 12

Close-up of mycelium.

mushrooms themselves serve as nourishment for worms, insects, mammals, bacteria, and other parasitic fungi. I believe that the occurrence and decomposition of a mushroom predetermines the nature and temporal biodiversity of downstream plant communities that naturally follow.

Whenever a catastrophe creates a field of debris—whether from overturned 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 to hold 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 mushrooms (Hawksworth 2001), and only about 10 percent of the mushroom 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 roles 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 their fungal allies, without which the life-support 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 53). 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 hundreds of toxic pesticides, fungicides, and petrochemicals were born in the laboratory. When these xenobiotics were released into nature, they often had immediate and initially desirable effects on their targets. However, events in the past few decades have shown that many of these inventions were in fact the crucibles of calamity, exacting a heavy toll on the biosphere. We have now learned that we must tread softly on the web of life, lest we alter it with adverse [illegible].

Toxic fungicides, like modified atrazine, once touted not only harm targeted species but also cause targeted organisms and their food chains and weaken the ozone layer. Resistance eventually emerges, and a temporary solution until tolerance is achieved. When the natural habitats of fungi have been repressed, the persistent need for chemical fertilizers increases, creating a cycle of chemical dependence, ultimately eroding sustainability. However, we can create mycologically sustainable environments by introducing, planting, or fostering fungi (mycorrhizal and endophytic) in combination with mulching with saprophytic mushroom mycelia. The results of these fungal activities include healthier soil, biodynamic communities, and enhanced cycles of renewal. With every gain in soil depth increases, 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. We are rapidly destroying our life-support ecosystems, a trend tantamount to suicide. By using fungi in filtration, we can reduce the environmental damage inflicted by humans by accelerating organic decomposition of the massive fields of debris we create—through everything from clear-cutting 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 return cycles, causing crop failures, global warming, climate change and, in a worst-case scenario, quickening the march towards ecocatastrophes of our own making. 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 return into balance with nature using mycelium to regulate the flow of nutrients. The use of mycological medicine is important. Now is the time to ensure the future of our planet and our species by partnering, or forming, with mycelium.

CHAPTER 2

The Mushroom Life Cycle

For people to use mycelium as healing membranes, a better understanding of the mushroom life cycle is helpful. Although we notice mushrooms when they pop up, their sudden appearance is the culmination 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 most other organisms coexisting in the same habitat. With each new mystery revealed, the [illegible]-less of our ecology expands, and our knowledge slowly 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 microscopic spores, visible en masse when they collect on a surface. When the moisture, temperature, and nutrients are right, spores freed from a mushroom (essentially mushroom seeds) 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 begins gathering nutrients and moisture. Once the mycelium is well developed it aggregates to form a primordium, called [illegible] ... Under optimal conditions, the transformation from spore to mycelium to 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]