MYCELIUM RUNNING

MYCELIUM RUNNING

How Mushrooms Can Help Save the World

PAUL STAMETS

TEN SPEED PRESS
Berkeley

Copyright © 2005 by Paul Stamets
Front cover illustration © 2005 by [illegible]

All rights reserved. Published in the United States by Ten Speed Press, an imprint of the Crown Publishing Group, a division of Random House, Inc., New York
www.crownpublishing.com
www.tenspeed.com

Ten Speed Press and the Ten Speed Press colophon are registered trademarks of Random House, Inc.

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
579.1'63—dc22 2005015986

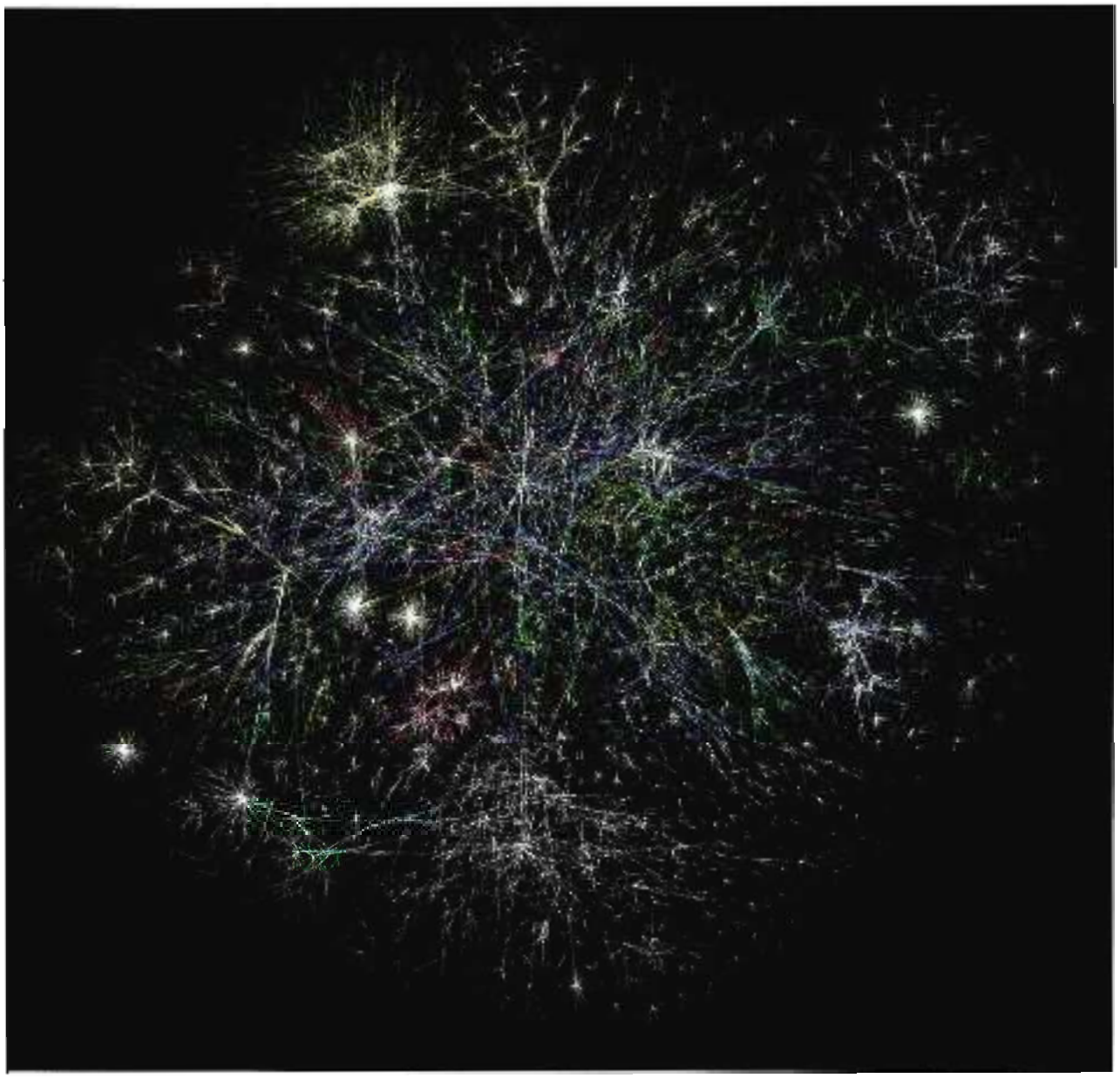
ISBN 978-1-58008-579-3
Printed in China through Colorcraft Ltd., Hong Kong

Cover design by Betsy Stromberg and Andrew [illegible]
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 [illegible] people who eat mushrooms do so at their own risk. This material is intended for educational purposes only and is not a substitute for consulting 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 fungi—or, more, at least with mycelium, the network of fungal threads in soil that acts as interfaces between plant roots and nutrients?

A mushroom is the reproductive structure or fruiting body of mycelium. Mycelium runs through our world, enhancing many other forms of life, and it is hidden and unexpected, a strange life form that has not attracted the attention scientists give to more familiar organisms of 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 chemical defenses, a range of antibiotics that are often active 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 fungal species, 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 as 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 components. 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 last possibility is

especially impressive because it has the potential to control insect pests like termites and fire ants by means that are completely nontoxic to human beings. Paul Stamets's work [illegible] and I look forward to seeing his inventions put to use.

As a physician and a 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 [illegible] decades of [illegible]. I [illegible] 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), 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 help us reconnect to nature in profound ways. Mushrooms, environmental stewards, 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 I call "mycorestoration." This book's 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 and treat contaminants. Mycoforestry uses mycelium and mushrooms to enhance forest health. Mycoremediation denatures toxins. Mycopesticides elects 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 simply mycology, I hope this book will be as useful as it is revolutionary. Those already active in bioremediation, ecoforestry, sustainable agriculture, permaculture, physicians, scientists, [illegible] are personally [illegible]. I hope this book enriches your 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, entered fungus into your diet, relished a fresh-picked matsutake grilled over an open fire, or tested a mushroom-based medicine, I hope you will find this book—and my pragmatic views on mycology—[illegible] beneficial—informative and inspiring. I contend that the planet's health actually depends on our respect for 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 LaDena for all your help with my field work and fungal projects. To my brother Bill, I thank you for years of [illegible] and sharing ideas [illegible] that helped focus my vision. I am also grateful to Meghan Keeffe, Karen O'Donnell Stein, [illegible], [illegible] Penner, and Betsy Steenberg for their help in editorial comments and research [illegible] digital images [illegible] production of this book. To my family, especially my mother and late father, I am grateful. [illegible] supported me with [illegible] love and [illegible] scientific curiosity. To Bill Wyss and Jo Ann Clark, thank you for placing your faith in me. To David Sumerlin, Steve Chadwick, Jimmy Gibson, David Brigham, Andrew Lefevre, Mark Minick, Damon Park, Natasha Ruiz, Kevin Scheuneman, [illegible], George Osgood, Alex Winstead, and the other employees of 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 [illegible] and their mycoremediation team, including Jack Word, Susan Thomas, Ann Drum, Meg Pinza, Pete Becker, and others are acknowledged for their contributions. [illegible] and Cindy Glenn of Texas A&M University [illegible] for their work on the [illegible] project. [illegible], William Hess, [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 into the annals of mycologists, from [illegible] to [illegible] whose [illegible] experience [illegible] the [illegible] that has become the springboard for the [illegible] revolution. Last, I am humbled by the [illegible] who have [illegible] spirit [illegible]. May future generations continue to [illegible] 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, bacteria, and protozoa 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 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 formed, fungi were in the vanguard. As generations 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 sentient cellular membranes. Fine, cobweb-like threads of mycelium channel nutrients from great distances to form fast-growing mushrooms. Mycelium, considerably slower, 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 mushroom mycelium as spawn, for both short- and long-term benefits. Mushroom spawn helps us recycle garden waste, wood, and yard debris, thereby creating mycological landscapes 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 forces of random genomic mutation 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] global warming.

I wonder what would happen if there were a Gaian Organization of Organisms (GOO), comprised from all of life, 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 equip us with tools to act responsibly and repair our shared environment, leading the way to habitat recovery. Knowing 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 expand 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 testament 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 cells. 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-

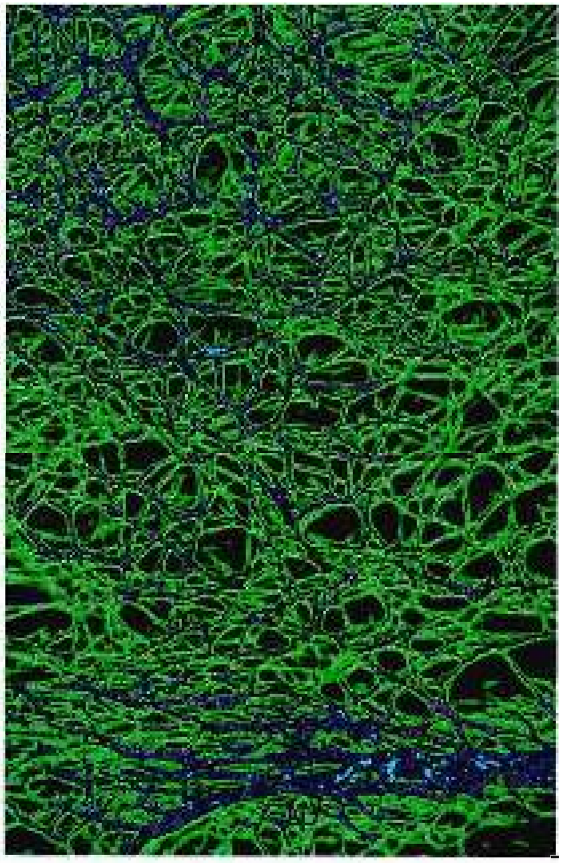


FIGURE 1

The mycelial network is composed of a membranous mat of ever-growing, continuously branching cell chains only one cell wall thick.

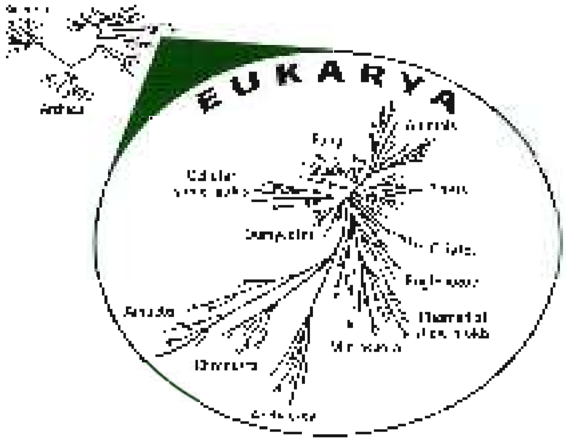


FIGURE A

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 this one taxonomic canopy (Baldauf et al. 2003).

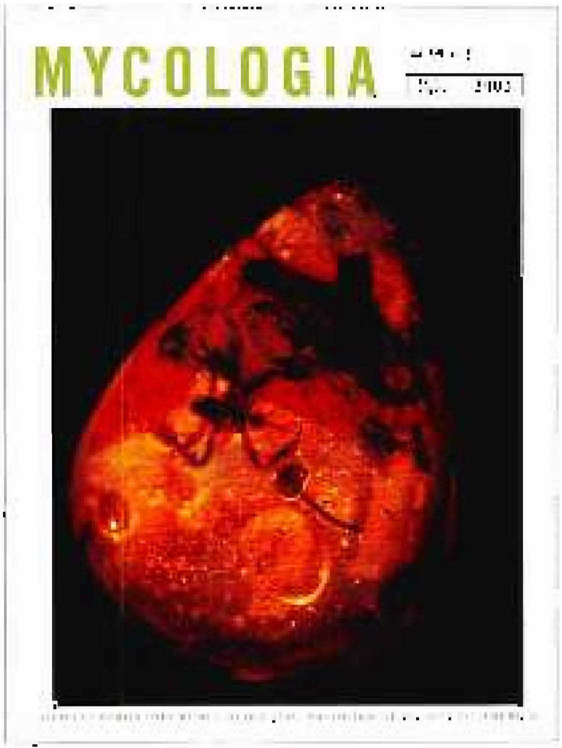
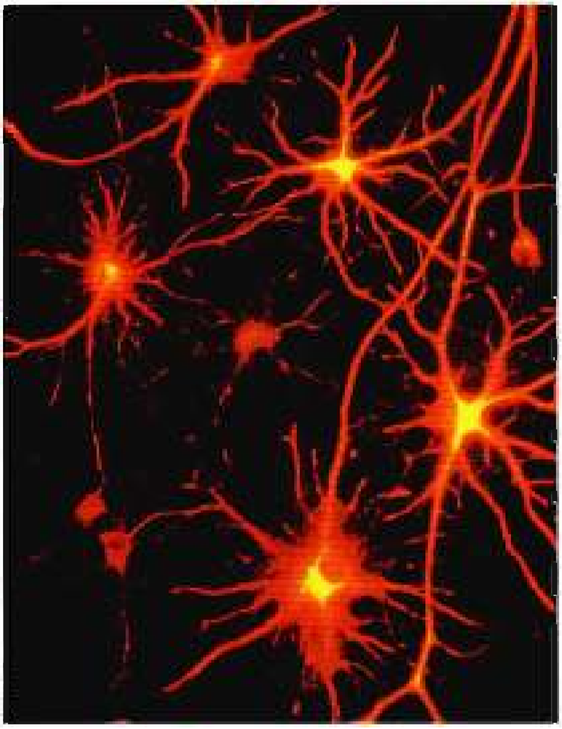


FIGURE 2

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 branch of fungi leading to animals evolved to envelop nutrients by surrounding them with a cell membrane, 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 a different 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. Fossil records show fires, toxic gases, and smoke from more than a thousand miles of volcanic vents enveloping 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 mountains of organic debris fields. The era of dinosaurs began and then ended 185 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 preceded this second catastrophic event. (The oldest known mushroom—encased in amber—

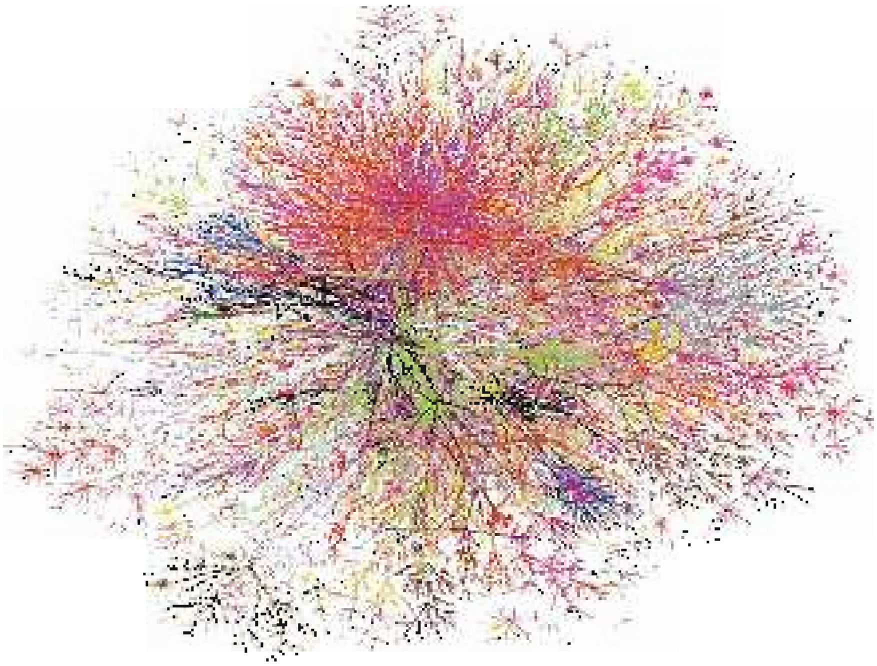


▲ FIGURE 3

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

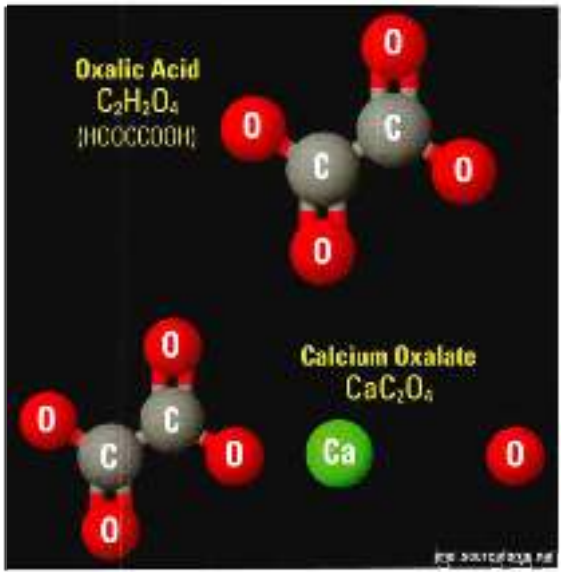
collected in New Jersey, dates from Cretaceous times, 92 to 94 million years ago. Mushrooms evolved their basic forms well before the most distant mammalian ancestors of humans.) Mycelium steers the course of ecosystems by forming mosaics of species. Ultimately, mycelium creates its own soil environment for its benefit, giving ecosystems the tools to endure.

Earth doctor James Lovelock, together with Lynn Margulis, came up with the Gaia hypothesis, which postulated that the Earth's biosphere intelligently interacts 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 nets, 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. Calcium oxalate crystals are formed by the mycelia of primary fungi. Oxalic acid minerals in rock or combining with calcium and manganese minerals to form oxalates. In this case calcium oxalate. Calcium oxalate sequesters two carbon dioxide molecules. Carbon dioxide from mushroom mycelia unfolding and bores feed weed, crumbling rocks as they grow, creating dynamic soils that support various populations of organisms. Below: Scanning electron micrograph of calcium oxalate crystals forming (pore mycelium

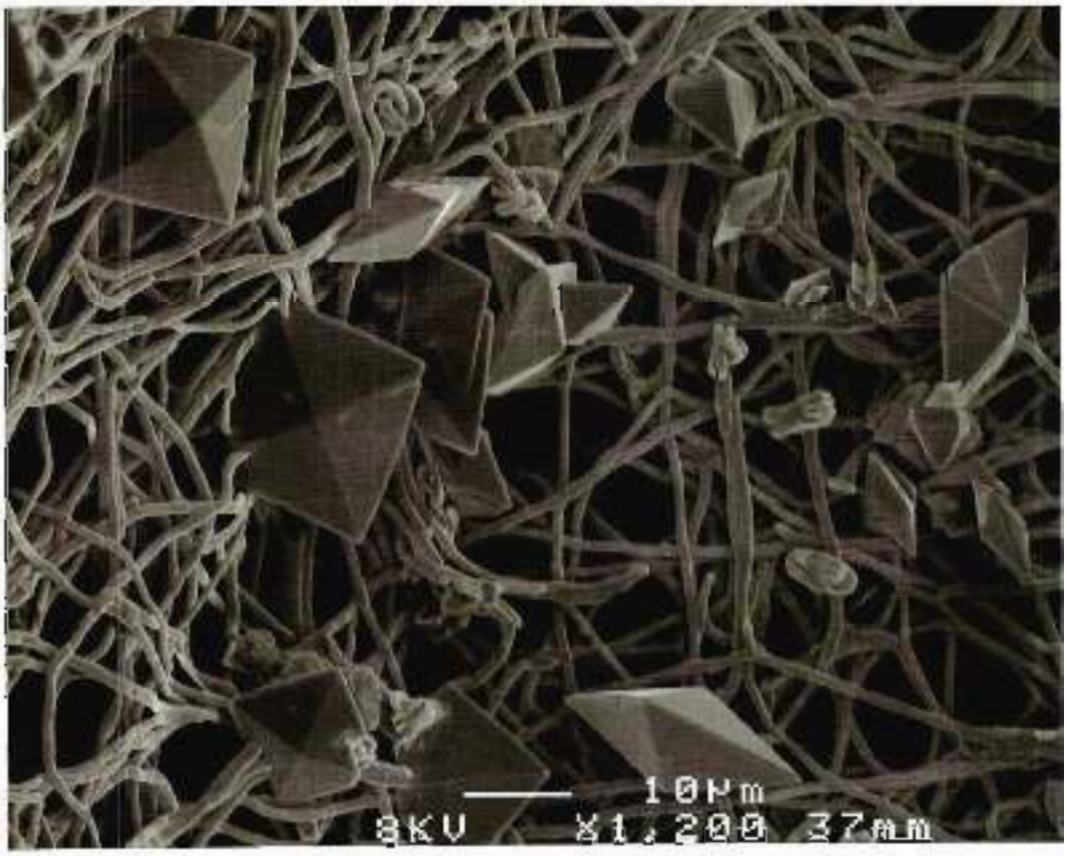


FIGURE D

Prototaxites was the name given to the fossil—measuring up to 1 meter wide and 8 meters tall—common approximately 420 million years ago, existing 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 earth. Known to the scientific world since first described in 1859, this fossil remained a mystery until C. Kevin Boyce and others proved that it was a giant fungus in 2007.

FIGURE E

Artist's depiction of Prototaxites, which was the tallest known organism on land at that time, as an observer standing nearby. The tallest plants then found near Prototaxites were less than a meter high.

sense. I especially feel that [illegible] upon entering a forest [illegible] These sensitive mycelial membranes act as a collective fungal consciousness. As mycelia are absolutely huge, [illegible] 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 externalized 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.

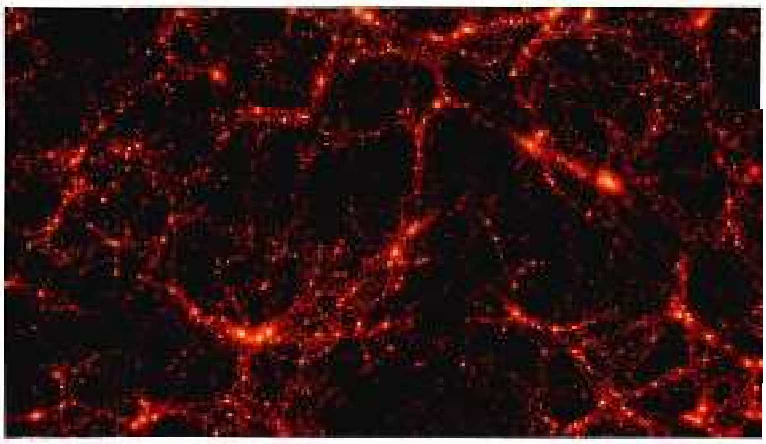
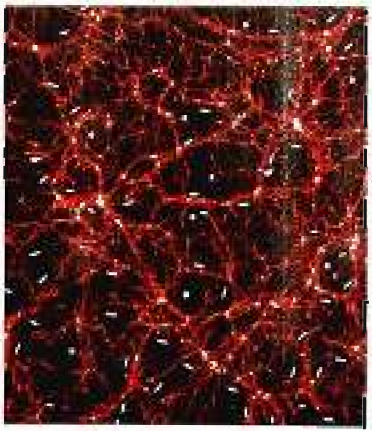


FIGURE 7

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 invisible threads. Note the galaxies interspersed throughout the mycelium-like network.

FIGURE 6

Computer model of the early universe [illegible]



▲ 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.

organisms through the landscape. A new Bioneuristic science could be born, dedicated to programming myco-ecological 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, if not for the work by researchers like Toshiyuki Nakagaki (2000). He created a maze over a petri dish filled with the nutrient agar and introduced small 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 Tokyo colleagues. 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 can be intelligent. They may have potential as smart allies, perhaps being programmed to collect environmental data (as suggested above), or to communicate with silicon chips in a computer interface. Envisioning fungi as instruments 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 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 perturbations.

▲ 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 60 for a larger patch of *Armillaria*, the largest organism in the world.)

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, indicating that life could have evolved there and become extinct several times over (Savage et al. 2003). (It was 1.5 then

FIGURE 10

Hurricane Isabel as viewed aboard the [illegible] on September 2002.

FIGURE 11

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

The Mycelial Archetype

When the Internet was designed, its exponential structure maximized the pooling of data and reserves of 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, also seen in the human brain. Diagrams of computer networks bear resemblance to both mycelium and neurological maps in the human mind (see figures 9 and 10). Our understanding of information networks in their many forms will lead to increased breakthroughs in 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. The density is such 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 slow waves, through dancing bacteria and swimming protozoa with nematodes sailing like whales through a microcosmic sea of life.

Environmentally, 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 successions. While mycelium nourishes plants, mushrooms then become nutrient centers for worms, insects, mammals, bacteria, and other parasitic fungi. I believe that the occurrence and decomposition of a mushroom predetermines the nutritional and temporal flow of downstream species consumers that it attracts.

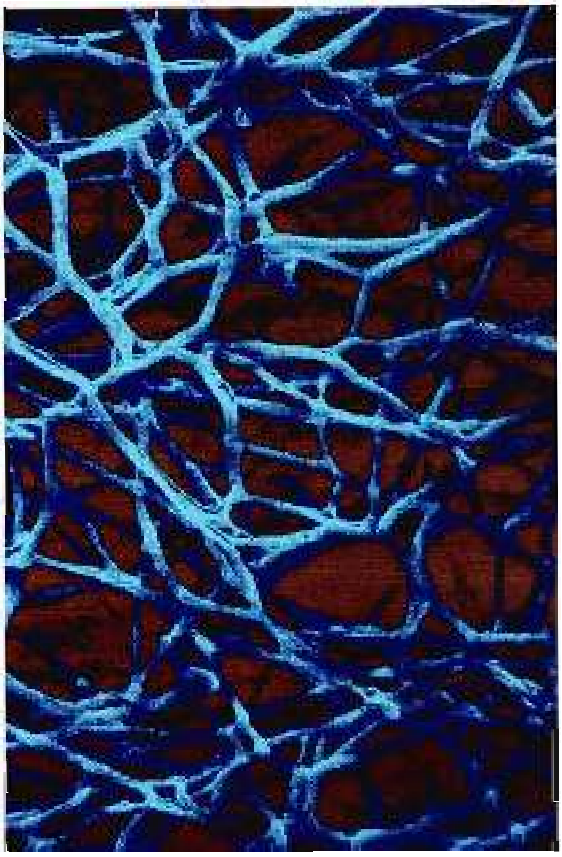


FIGURE 12

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 mushrooms (Hawksworth 2001), and only about 10 percent of the estimated mushroom species have been identified, meaning that our taxonomic knowledge of mushrooms is exceeded by our ignorance by at least one order of magnitude. This surprising diversity of fungi speaks to the essentials 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 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 13). In the case 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 wave of new pesticides, fungicides, and petrochemicals were born in the laboratory. When these synthetics were released into nature, they often had dramatic 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 cause of serious pollution, taking a heavy toll on the biosphere. We have now learned that we must tread softly on the web of life, or else it will unravel beneath us.

Toxic fungicides, like methyl bromide, once touted not only to harm target species but also non-targeted organisms and toxic food chains and threaten the ozone layer. These are examples of a temporary solution until tolerance is achieved. When the natural benefits of fungi have been repressed, the perceived need for added fertilizers increases, creating a cycle of chemical dependency, ultimately eroding sustainability. However, we can create mycologically sustainable environments by introducing pioneering fungi (mycorrhizal and endophytic) in conjunction with mulching with saprophytic mushroom mycelia. The results of these fungal activities include healthier soils, 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. Enlisting fungal mycelia, 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 nutrient cycles, causing crop failures, global warming, climate change, and, in a worst-case scenario, quickening the march towards eco-catastrophes 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 come into balance with nature using mycelium to regulate the flow of nutrients. The use of mycological medicine is opportune. Now is the time to ensure the future of our planet and our species by partnering, or returning, with mycelium.

CHAPTER 2

The Mushroom Life Cycle

For [illegible] to use [illegible] as healing membranes, a better understanding of the mushroom life cycle is helpful. Although we notice mushrooms when they pop up, their underlying mycelium and its vast array of cellular events is 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 those other organisms coexisting in the same habitat. With each new niche revealed, the boundaries of mycology expand, and our knowledge base 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 at first when they collect en masse. 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, after gathering nutrients and moisture, [illegible] aggregate to form a primordium, called the "[illegible]," [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 [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

- *read online Using R for Data Management, Statistical Analysis, and Graphics*
- read The Intimate Bond: How Animals Shaped Human History
- Dylan Goes Electric!: Newport, Seeger, Dylan, and the Night that Split the Sixties book
- download online Racconti
- click Mr. Mercedes

- http://cavalldecartro.highlandagency.es/library/Using-R-for-Data-Management--Statistical-Analysis--and-Graphics.pdf
- http://weddingcellist.com/lib/90--Tastefully-Simple-Recipes-Volume-1--Chicken--Pasta--Salmon-Box-Set-.pdf
- http://academialanguagebar.com/?ebooks/Pro-Python.pdf
- http://wind-in-herleshausen.de/?freebooks/Racconti.pdf
- http://nexson.arzamaszev.com/library/Mr--Mercedes.pdf