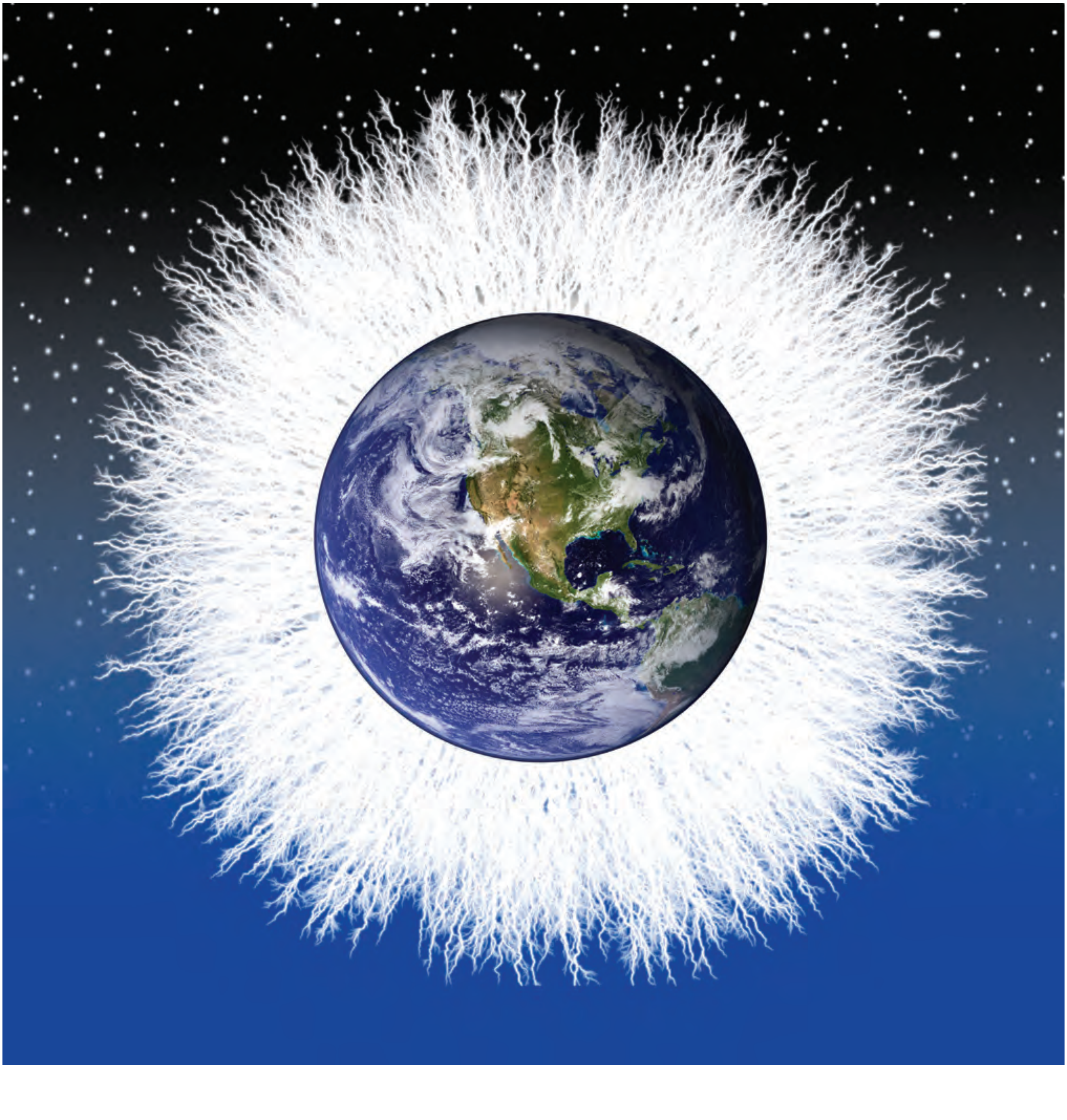
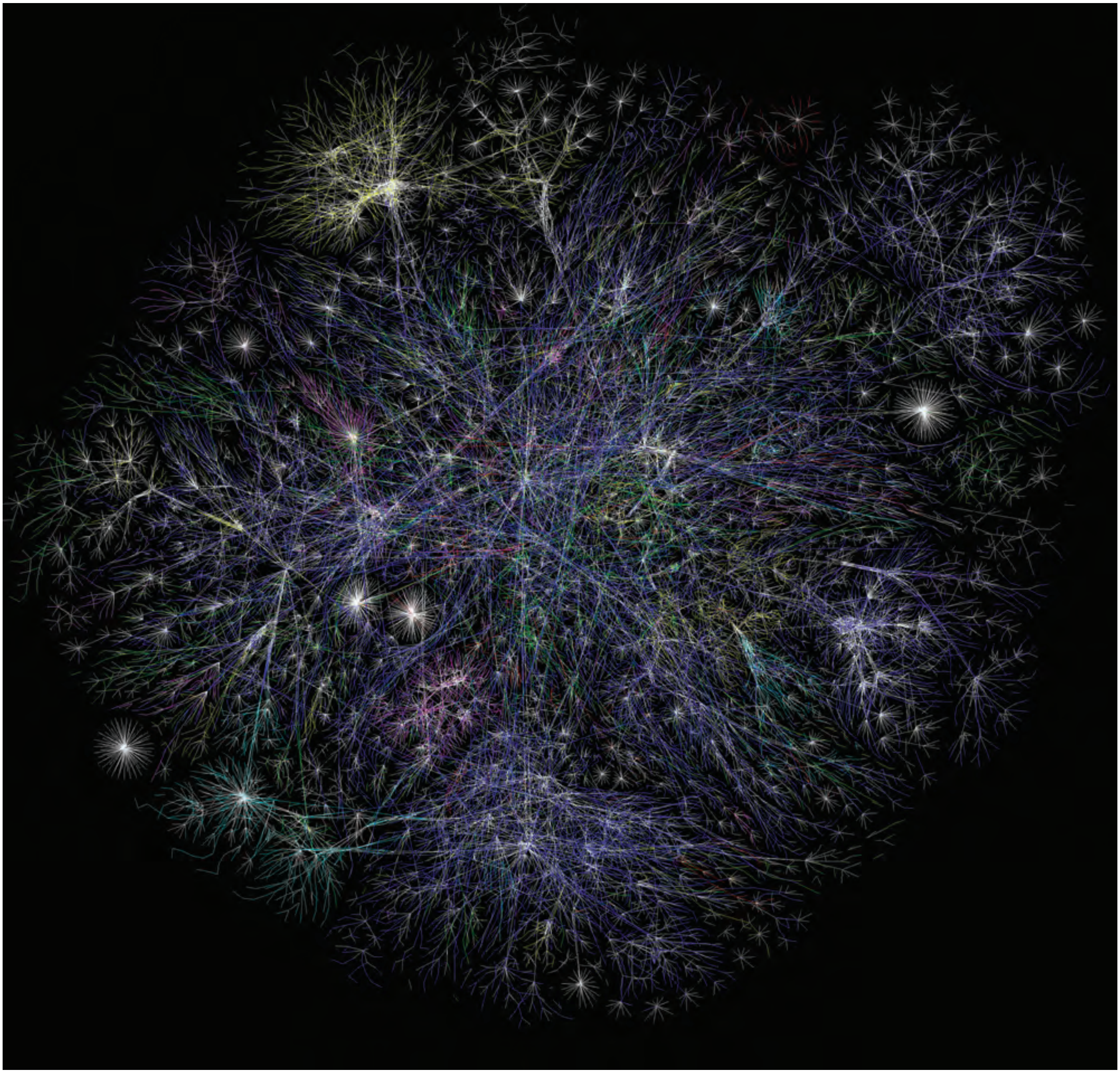
MYCELIUM RUNNING

How Mushrooms Can Help Save the World

PAUL STAMETS

VISUALS FROM THE BOOK





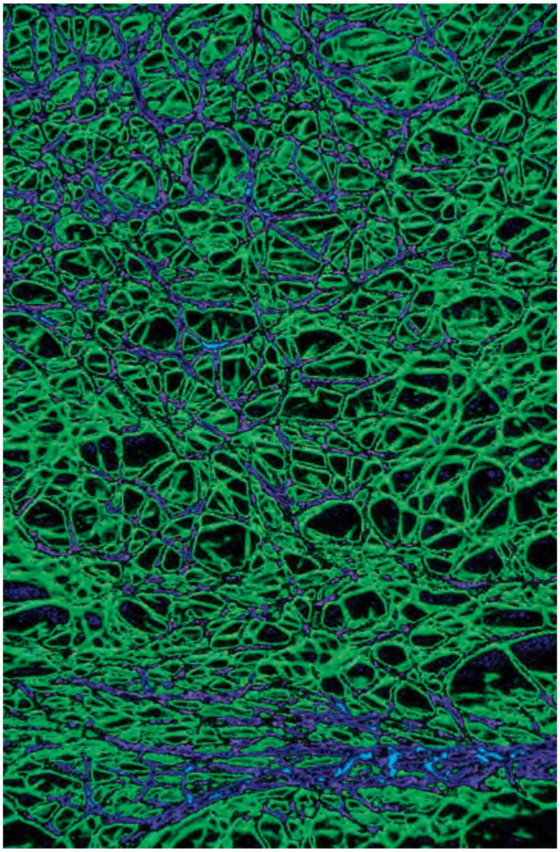


FIGURE 1

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

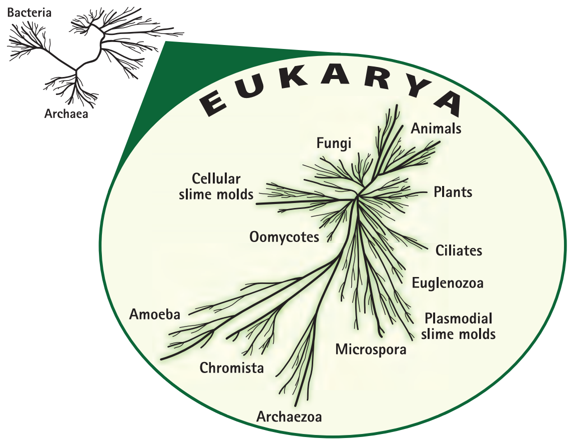


FIGURE A

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 this one taxonomic concept (Sina et al. 2005).

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 time and collected in the Dominican Republic. The oldest mushrooms in amber are estimated at 90 to 94 million years old.

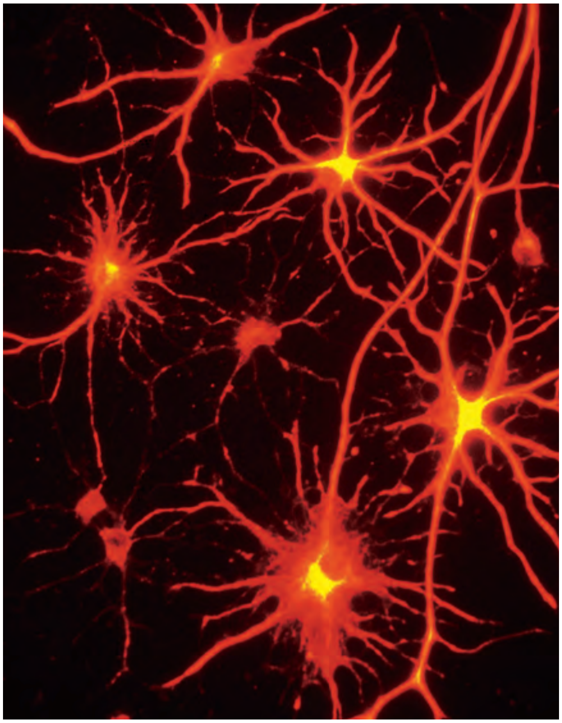
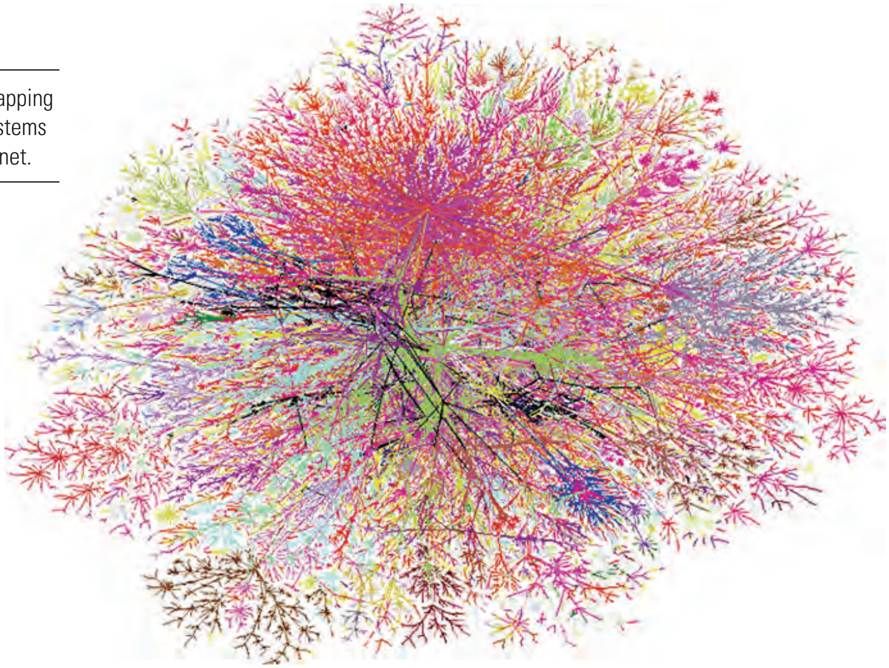


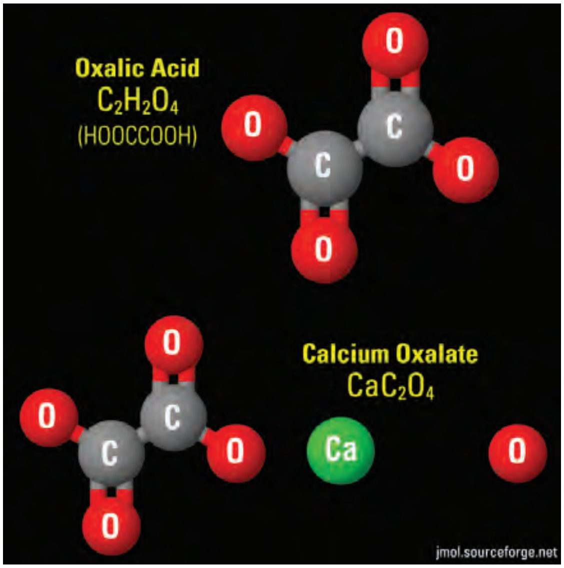
FIGURE 3

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

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. Carbon-rich 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.

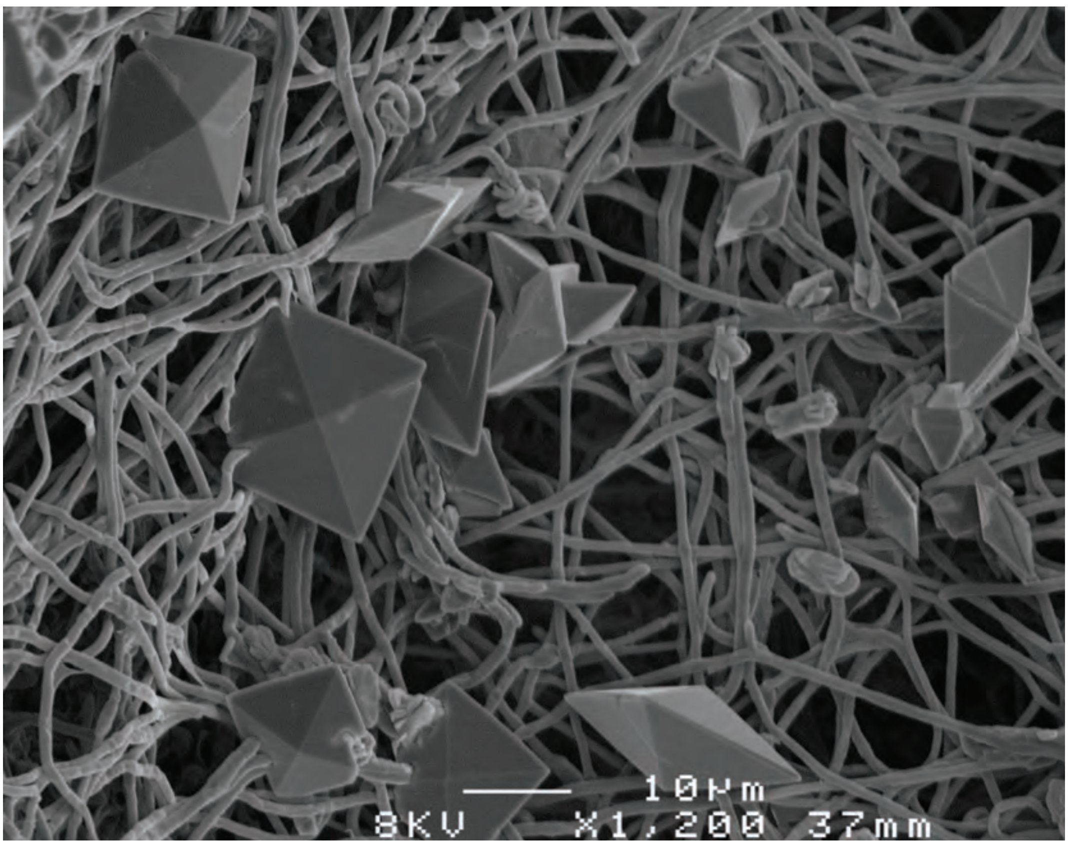


FIGURE D

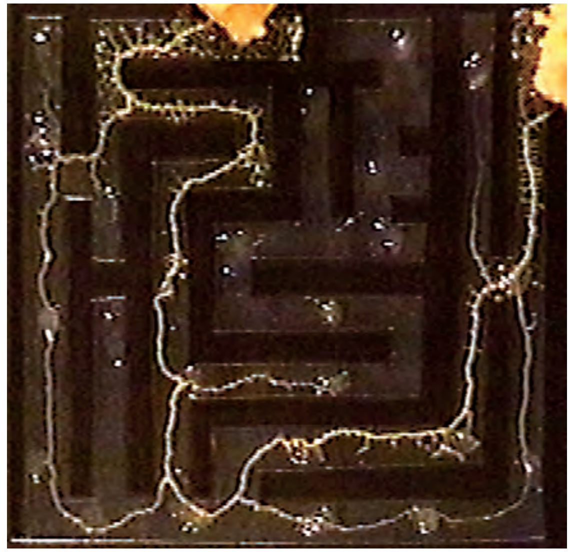
Prototaxites was the name given to this fossil—a remnant of a life form approximately 420 million years old, existing at the end of the late Silurian and through the beginning of the Devonian periods. Found in Canada and Saudi Arabia, this organism was widespread across the landscapes of the Paleozoic era. 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 depiction of Prototaxites, which was the tallest known organism on land in its time, laying down or standing upright. The tallest plants, featured next to Prototaxites, were less than a meter high.

FIGURE 5

A slime mold, *Physarum polycephalum,* chooses the shortest route between 2 food sources in a maze, disregarding dead ends. In a controversial article, Toshuyiki Nakagaki proposes that this represents a form of cellular intelligence.



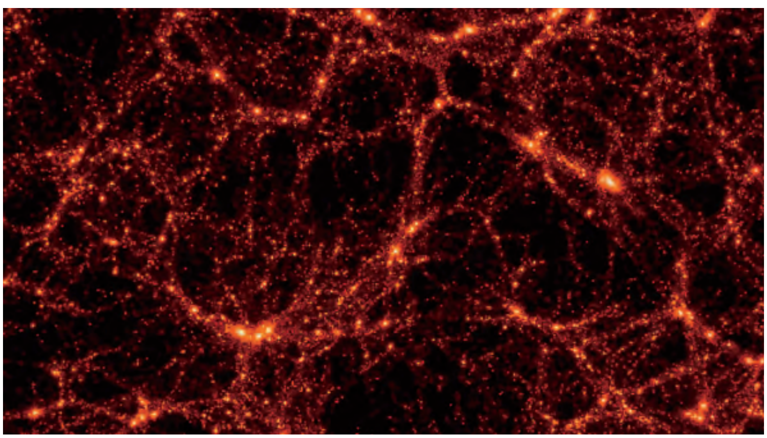


FIGURE 6

Computer model of the early universe. These primeval filaments in space resemble the mycelial archetype.

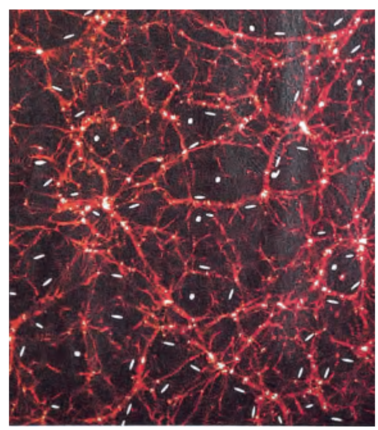


FIGURE 7

Computer model of dark matter in universe. In a conjunct of string theory, more than 96 percent of the mass of the universe is theorized to be composed of these molecular threads. Note the galaxies interspersed throughout the myceliumlike matrix.

FIGURE 8

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

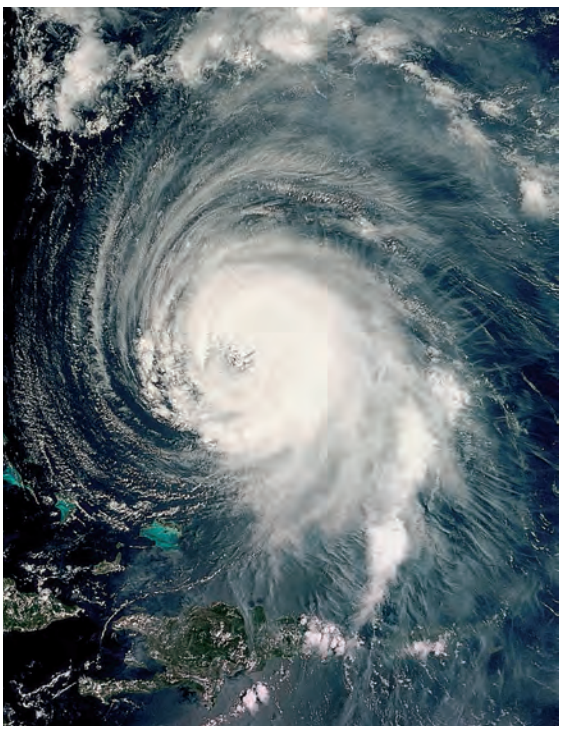


FIGURE 10

Hurricane Isabella approaches North America in October 2003.

FIGURE 11

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

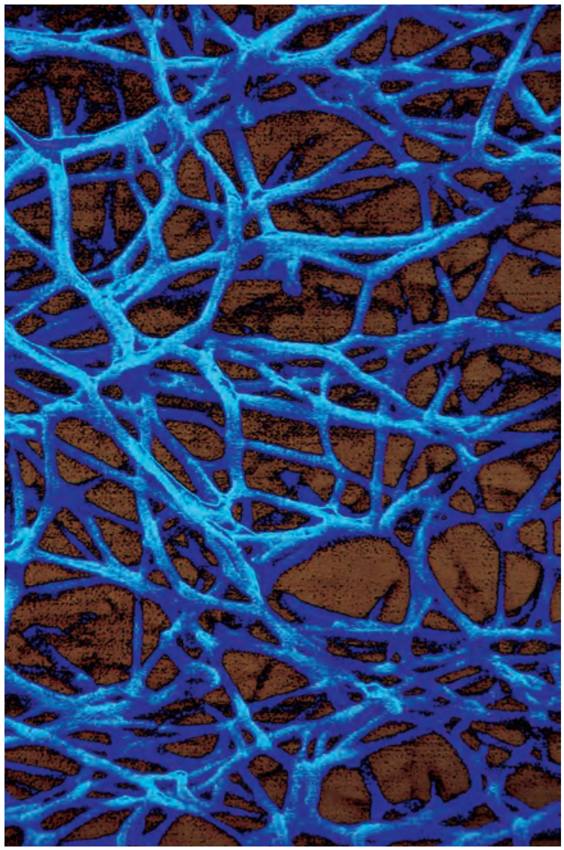


FIGURE 12

Close-up of mycelium.

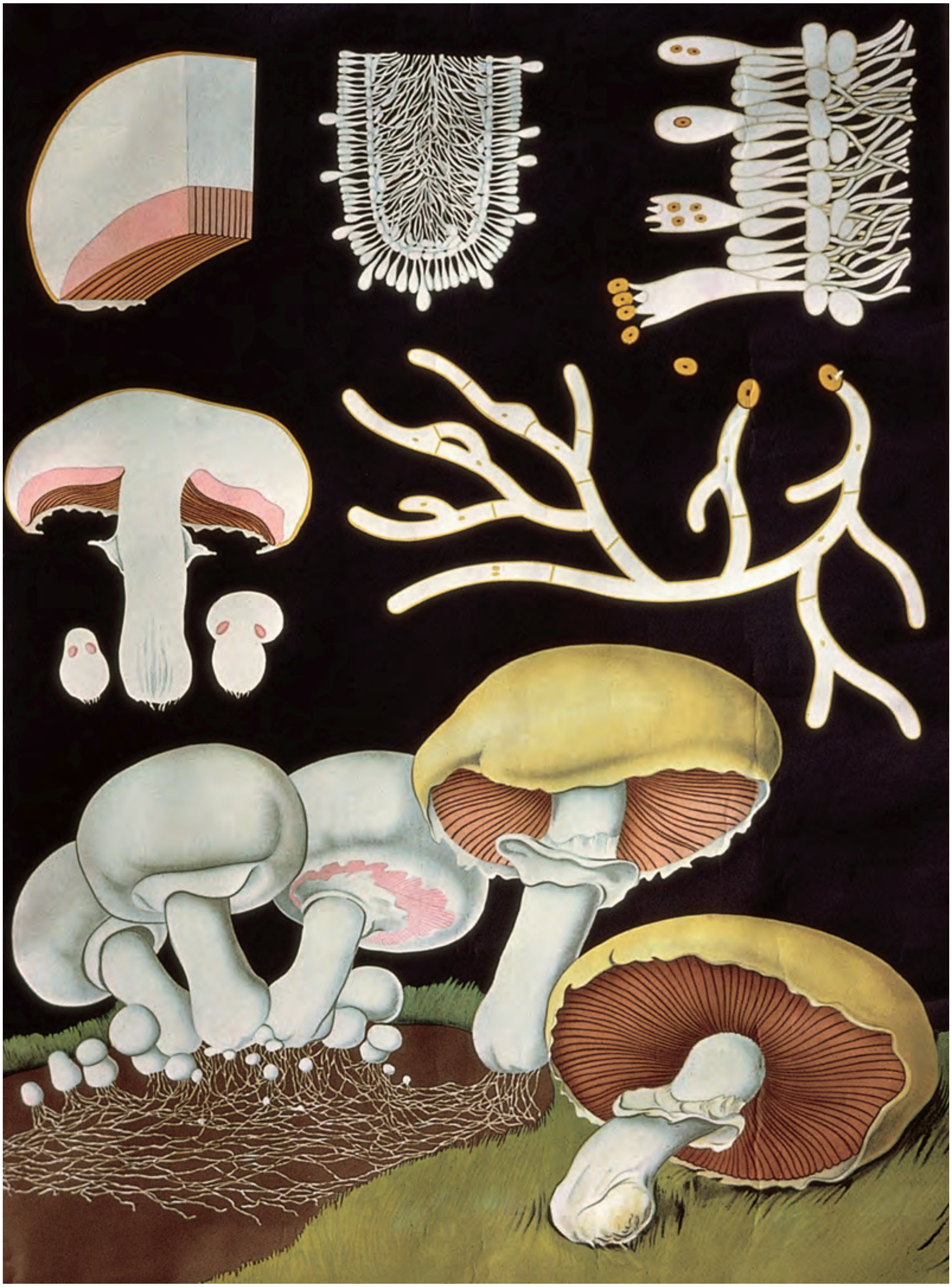


FIGURE 13

Depiction of the mushroom life cycle.

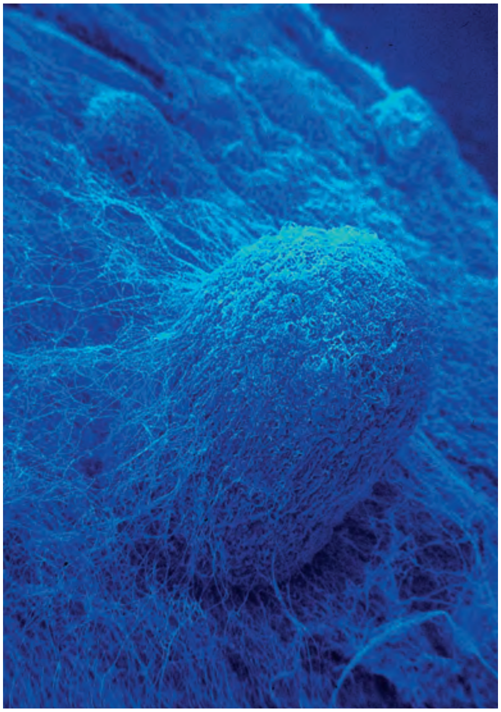


FIGURE 14

Scanning electron micrograph of primordium forming from a mycelial mat.

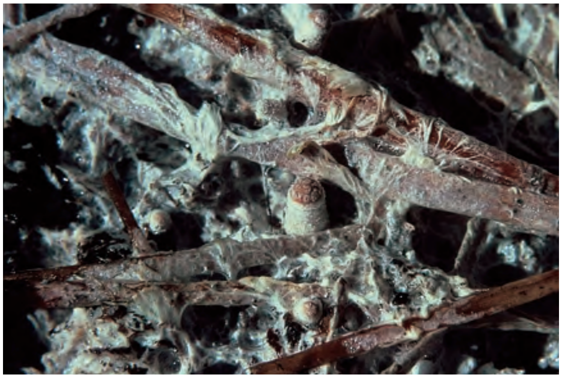


FIGURE 15

A baby mushroom is called a *primordium,* a stage between mycelium and mature mushroom.

FIGURE 16

An example of an indeterminant mushroom species, a *Ganoderma,* perhaps *Ganoderma curtisii,* a sister species to reishi *(Ganoderma lucidum).* The mushrooms formed and grew around twigs and grass—the latter of which remains green, vibrant, and healthy, despite being surrounded by fungal tissue, a phenomenom I find peculiar, and biologically interesting.

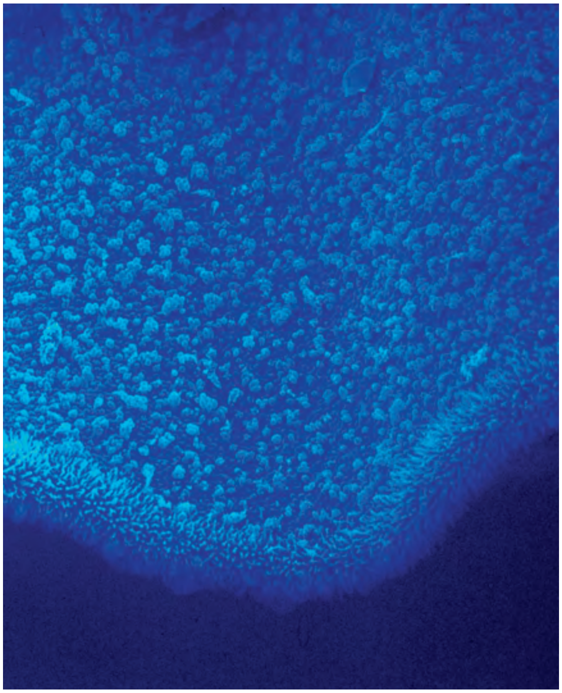


FIGURE 17

Low magnification of a mushroom gill plate showing the gill edge and surface plane populated with spore-producing basidia.

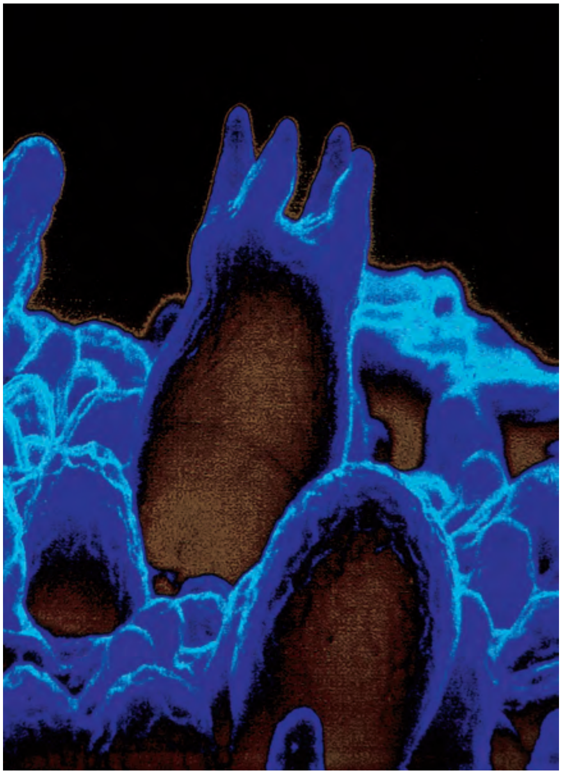


FIGURE 18

Emerging young basidium.

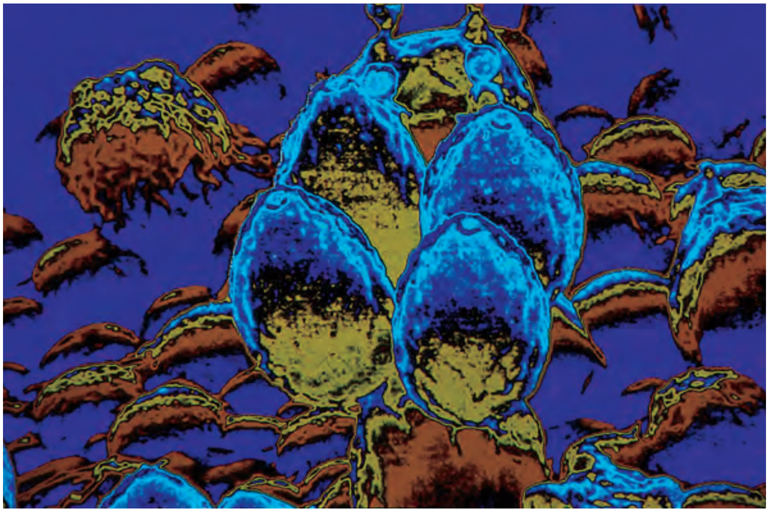


FIGURE 19

Mature basidium just before spore release.

FIGURE 20

Cedar Cividanes reaches upward to touch the underside of a large specimen of the artist conk *(Ganoderma applanatum)* in the old-growth forest of the Duckabush River basin. In the Pacific Northwest, this mushroom produces prodigious quantities of spores from late spring through early fall.

FIGURE 21

From the artist conk featured in the previous image, we took a thumbnail-size slice of tissue back to the laboratory, where we broke it in half, cut out a tiny fragment, and transferred it to a nutrient-filled petri dish to start a culture. The resulting mushroom that grew is genetically identical to the wild artist conk from which it came. The original mushroom, whose small wound soon healed over, still survives in the old-growth forest. I encourage such low-impact practices for collecting cultures without removing the mushrooms from their ecosystem.

➤ FIGURES 22, 23, AND 24

After a *Russula* mushroom climaxes and disintegrates, its spores germinate into a mycelial matrix. Days later, the mycelium spreads from the disintegrated parent mushroom's corpse, forming a mycelial network. Such surface mycelia soon submerge into the duff or soil, disappearing from view. Mycelia can be found under practically any log, stick, bale of straw, cardboard, or other organic material on the ground. In a gram of this myceliated soil, more than 1 mile of cells form; in a cubic inch more than 8 miles. In this photo, my hiking boot covers approximately 300 miles of mycelium. Hence from a mycelium's point of reference, a journey of 10,000 miles is only 33 plus footsteps!

FIGURES 25, 26, AND 27

The path of decomposition: wood chips; wood chips colonized by mycelium; myceliated wood chips after digestion by worms and other organisms.

FIGURE 28

Turkey tail *(Trametes versicolor)* fruiting on a conifer log deep in old-growth forest in Olympic National Park.

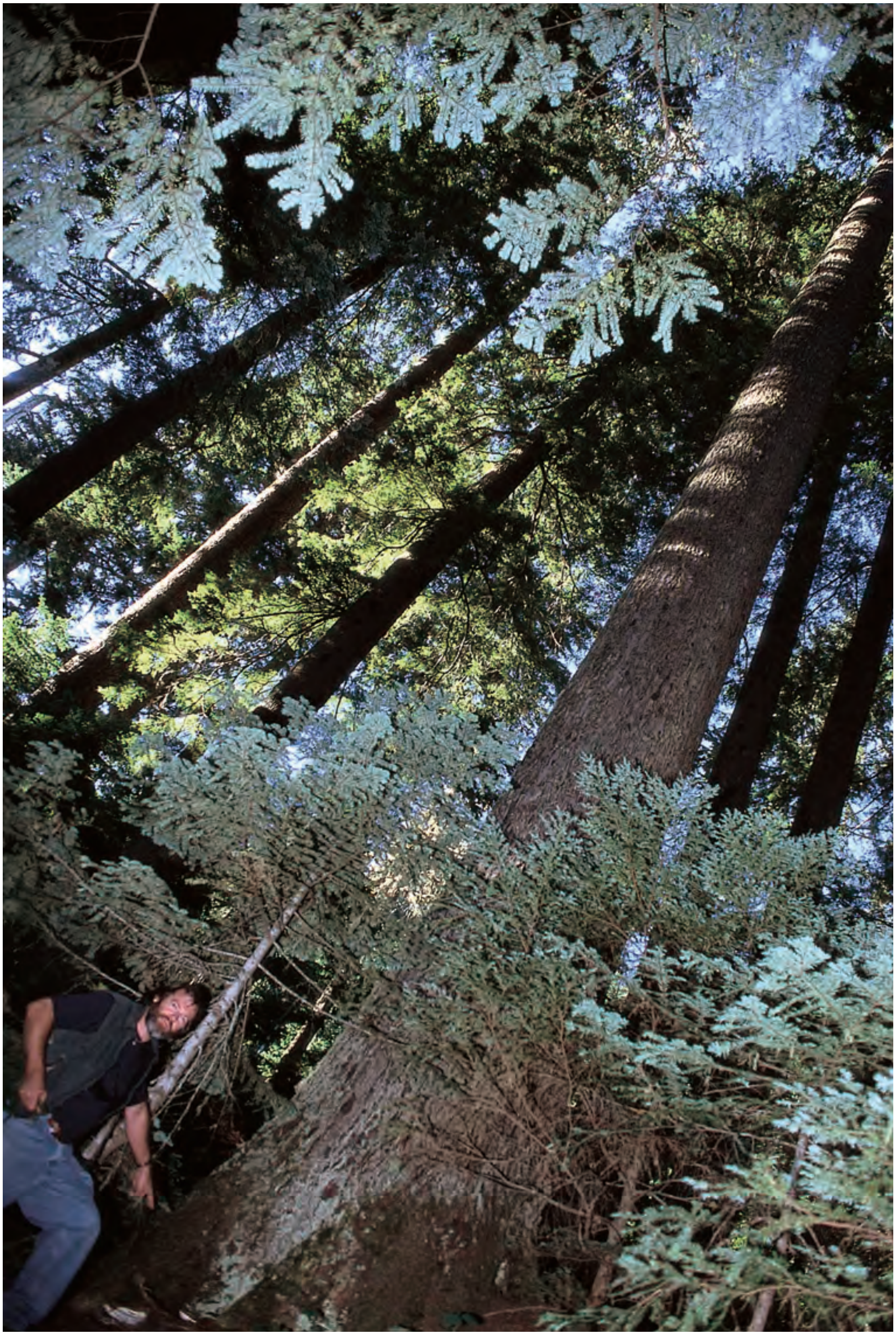


FIGURE 29

These towering old-growth trees near Mount Rainier, grow out of thin soil but gather nutrients from afar from their mycelium-supported roots. In fact, most plants are supported by vast and complex colonies of fungi working in concert. Here I point to *Bridgeoporus nobilissimus* (for a closer view see figure 50), a mushroom exclusive to old-growth habitat and the first fungus to be listed as an endangered species.

FIGURE 30

David Arora, author of *Mushrooms Demystified* and *All That the Rain Promises and More* is positioned to take a photograph of a family of ambiguous Stropharias, *Stropharia ambigua,* near my home.

FIGURE 31

My daughter, La Dena Stamets, sits beside the garden giant *(Stropharia rugoso annulata),* which is deep burgundy in color when young and fades as it matures, sometimes achieving a majestic stature. This mushroom can be both a primary and a secondary saprophyte but is dependent upon soil microbes for fruiting.

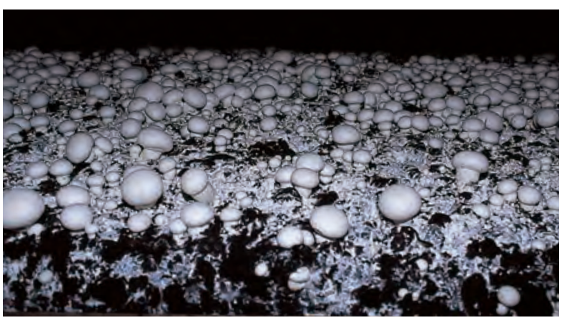


FIGURE 32

Commercial button mushroom *(Agaricus bisporus)* cultivation in Holland. This mushroom is a classic secondary saprophyte, growing on compost.

FIGURE 33

The honey mushroom *(Armillaria ostoyae)* fruiting from a stump.

FIGURE 34

Matsutake, which are mycorrhizal mushrooms known to mycologists as *Tricholoma magnivelare,* growing deep in the old-growth forest of Washington State.

FIGURE 35

Dusty Yao happily holds her harvest of wild porcinis, the mycorrhizal *Boletus edulis,* collected in the mountains above Telluride, Colorado.

FIGURE 36

Jim Gouin is pleased to find these delicious matsutakes *(Tricholoma magnivelare),* a mycorrhizal mushroom, in the mountains somewhere within 200 miles of Seattle, Washington.

FIGURE 37

Eureka! My basket awaits a bountiful collection of these apricot-smelling chanterelles, probably *Cantharellus formosus,* a mycorrhizal mushroom species growing in a 40-year-old Douglas fir forest near Olympia, Washington. My practice is to pick no more than 25 percent of the mushrooms of a wild patch, leaving young ones, and when encountering pairs of mushrooms, only pick one of them. Chanterelles tend to form as twins, so cutting one mushroom near to the ground saves the other twin, allowing it to mature, sporulate, and spread.

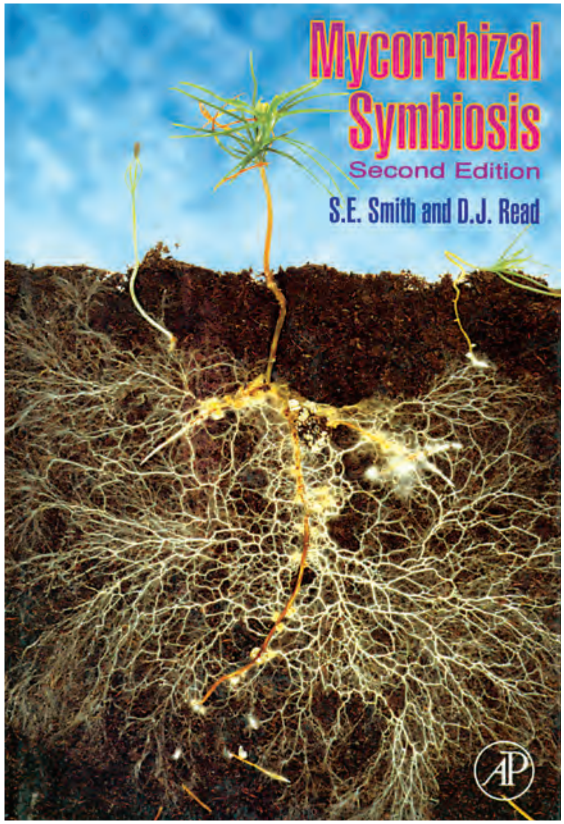


FIGURE 38

On the cover of this excellent book, the roots of a young pine tree *(Pinus sylvestris)* are enveloped with the mycelium of the mushroom *Suillus bovinus*. The mycelium extends the tree's range for absorbing nutrients and water while conferring a fungal defense against invasive diseases. This symbiotic pairing is the norm in nature, not the exception.

FIGURE 39

Bigleaf maples *(Acer macrophyllum)* grow in the rain forest of the Olympic Mountains, in Washington State. Research by Cobb et al. (2001) showed that this maple extends roots on its outer trunk that climb into the canopy, essentially creating a biosphere high above the forest floor. The biomass of these aerial roots is similar to the biomass of the subterranean roots. Upon these aerial roots, a complex habitat has evolved, including mosses (nonvascular epiphytes) and licorice ferns (*Polypodium glycyrrhiza;* a vascular epiphyte), once thought to be parasitic to the tree but now known to be part of the tree's healthy ecosystem.

FIGURE 40

The Perigord truffle *(Tuber melanosporum)*, is one of the most sought-after and highly regarded gourmet mushrooms in the world. This mushroom is mycorrhizal, growing in association with filberts and oak trees.

FIGURE 41

Truffle “brule” surrounds this filbert tree. As the mycelium of *Tuber melanosporum* consolidates its domain, the surrounding vegetation dies, creating a noticeable zone in the calcareous soils, a telltale sign that truffle mycelium has taken root.

FIGURE 42

Comparison of big leaf maples *(Acer macrophyllum)* without (smaller) and with (larger) mycorrhizae.

FIGURE 43

Termitomyces robustus, a delicious choice edible mushroom, sprouts from an aged, abandoned termite colony.

FIGURE 44

This giant mushroom, *Termitomyces* sp., is highly favored by the people of central Africa as a delicious edible. The primordium begin several feet underground, deep in a termite nest, extending upward as a long "taproot," and then forming a mushroom on the surface, especially when the nests are abandoned. How termites cultivate this mushroom has befuddled the best mycological minds in the world.

FIGURE 45

Trevon Stamets is excited to have his picture taken with the parasol mushroom *(Lepiota procera)* which is cultivated by ants to help them stave off infections. Many ants and termites farm fungi.

FIGURE 46

The tinder or amadou mushroom *(Fomes fomentarius)*, a species found predominantly on birch, is distributed throughout the boreal forests of the world.

FIGURE 47

Mycologist Jim Gouin in Quebec, Canada, with chaga, the aerial sclerotium of *Inonotus obliquus.*

FIGURE F

Psathyrella aquatica nom. prov. Until recently, conventional wisdom held that gilled mushrooms did not exist underwater. In 2005, this Psathyrella, a new species, was discovered in the clear, flowing, pristine waters of the Rogue River near Crater Lake, Oregon. (See Coffan, Southworth, and Frank, 2008, in press.) This discovery opens up a new branch of aquatic mycology, and raises many questions. How many other mushroom species grow underwater?

FIGURE 48

The health of a forest ecosystem's foundation is an interplay of mycelial networks from saprophytic, mycorrhizal, endophytic, and parasitic fungi.

FIGURE 49

Dusty Yao hunts medicinal mushrooms in the Olympics.

Some Commonly Collected Wild Edible Mushrooms from Northwestern North America*

Mushroom	Common Name
*Boletus edulis***	King bolete
*Cantharellus cibarius***	Chanterelle
*Cantharellus formosus***	Chanterelle
*Cantharellus subalbidus***	White chanterelle
*Coprinus comatus**	Shaggy mane
*Cortinarius caperatus***	Gypsy mushroom
*Craterellus cornucopiodes***	Horn of plenty
*Hydnum repandum***	Hedgehog
*Hypomyces lactifluorum****	Lobster
*Leccinum insigne***	Aspen bolete
Leccinum seabrum	Birch bolete
*Morchella elata**	Black morel
*Morchella esculenta**	Yellow or white morel
*Pleurotus ostreatus**	Oyster
*Polyozellus multiplex***	Blue chanterelle
*Sparassis crispa****	Cauliflower
*Tricholoma matsutake***	Pine mushroom
*Tuber gibbosum***	Oregon white truffle

* Species are saprophytes unless otherwise indicated.

** Mycorrhizal species, difficult to cultivate.

*** Nonmycorrhizal species, parasitic.

FIGURE 50

The author squats beside a massive noble polypore *(Bridgeoporus nobilissimus)* growing on a stump in the Oregon Cascades. This mushroom, 53 inches in diameter and estimated to weigh more than 300 pounds, is perhaps the largest of its kind in North America.

FIGURE 51

An unusual mushroom, the noble polypore *(Bridgeoporus nobilissimus)* hosts other plants and fungi. This young specimen, weighing several hundred pounds, is covered with a luxuriant coat of moss.

FIGURE 52

Dusty Yao with gargantuan *Phaeolepiota aurea* mushrooms deep in an old-growth forest in Washington State. These mushrooms stay erect and firm and resist rot for many weeks, suggesting to me that they could possess some powerful antibiotics.

FIGURE 53

Stainless steel tree cork borers can be used for removing a thin cylinder of tissue from a mushroom, in this case, a small agarikon mushroom *(Fomitopsis officinalis)* leaving the mushroom in the woods. The culture is taken from the layer just above the spore-producing polypored hymenial layer. For conks high in the air, lightweight tethered arrows whose tips are equipped with hollow metal shafts can be shot into the underside of the conk, to retrieve tissue for cloning with minimum impact.

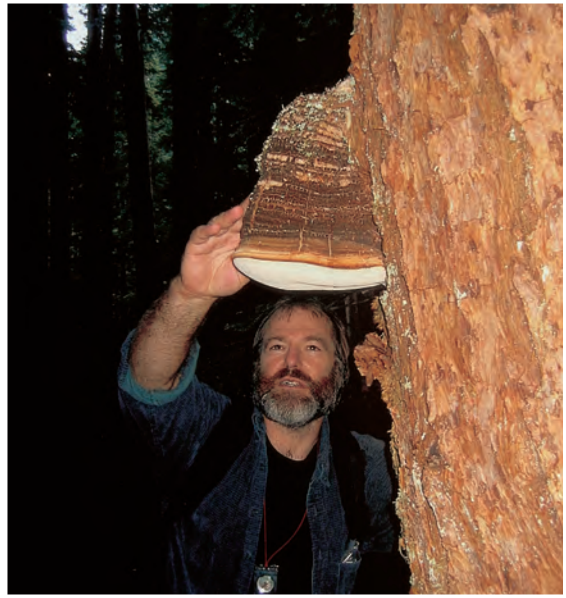


FIGURE 54

Agarikon *(Fomitopsis officinalis)* a mushroom found in the old-growth forests of the Olympic Peninsula in the Pacific Northwest. Extracts from the culture I generated from cloning this conk produced compounds very active against two pox viruses when screened through the Biodefense BioShield program administered jointly through the U.S. National Institutes of Health (NIH) and the U.S. Army Medical Research Institute of Infectious Diseases (USAMRIID), a coordinated effort to combat potentially weaponized viruses. The genome of this species may give rise to novel antivirals and hence should be protected. Although the mushrooms were not active when boiled in water, specially prepared extracts from living mycelium showed potent activity against vaccinia pox and cowpox viruses.

FIGURE 55

Another agarikon *(Fomitopsis officinalis)* collected in the central Cascades of Washington State. A specially prepared extract from this strain was very active against pox viruses. Strains appear to differ in their antipox activities.

FIGURE 56

Dusty Yao with necklace of soma *(Amanita muscaria).*

Cross-Index of Mushrooms and Targeted Therapeutic Effects

Each mushroom species has a unique chemistry and molecular architecture. Many species are now known to have medicinal properties useful for improving human health. Here is a short list of some of those properties.

	Antibacterial	Anti-Candida	Anti-inflammatory	Antioxidant	Antitumor	Antiviral	Blood Pressure	Blood Sugar Moderator	Cardiovascular	Cholesterol Reducer	Immune Enhancer	Kidney Tonic	Liver Tonic	Lungs/Respiratory	Nerve Tonic	Sexual Potentiator	Stress Reducer
Agaricus brasiliensis (Himematsutake)					X	X		X		X	X						
Cordyceps sinensis (Cordyceps)	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X
Flammulina velutipes (Enokitake)					X						X						
Fomes fomentarius (Ice Man Polypore)	X					X											
Ganoderma applanatum (Artist Conk)	X		X		X									X			
Ganoderma lucidum (Reishi/Ling Chi)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Ganoderma oregonense (Oregon Polypore)	X				X				X		X			X	X		
Grifola frondosa (Maitake/Hen of the Woods)	X	X			X	X	X	X			X			X	X		X
Hericium erinaceus (Yamabushitake/Lion's Mane)	X	X	X		X										X		
Inonotus obliquus (Chaga)	X		X		X	X		X			X		X				
Lentinula edodes (Shiitake)	X	X			X	X	X	X		X	X	X	X			X	X
Phellinus linteus (Mesima)	X		X			X											
Piptoporus betulinus (Birch Polypore)	X		X			X					X						
Pleurotus ostreatus (Hiratake/Pearl Oyster)	X					X	X		X	X					X		
Polyporus sulphureus (Chicken of the Woods)	X																
Polyporus umbellatus (Zhu Ling)	X		X		X	X					X		X	X			
Schizophyllum commune (Suehirotake/Split-Gill)		X			X	X											
Trametes versicolor (Yun Zhi/Turkey Tail)	X			X	X	X					X	X	X				

Mushrooms with Activity Against Specific Cancers

For the past 30 years, researchers have studied mushrooms' effectiveness against cancer. Some of their findings are summarized below.

	Breast	Cervical / Uterine	Colorectal	Gastric / Stomach	Leukemia	Liver	Lung	Lymphoma	Melanoma	Ovarian	Pancreatic	Prostate	Sarcoma
Agaricus brasiliensis		X	X										X
*Clitocybe illudens** *(Omphalotus olearius)*	X						X			X	X		X
Cordyceps sinensis					X		X	X					
Flammulina velutipes								X				X	
Ganoderma lucidum					X	X	X					X	X
Grifola frondosa	X		X		X	X	X					X	
Hericium erinaceus				X		X							
Inonotus obliquus		X											
Lentinula edodes	X					X			X			X	
Phellinus linteus		X	X	X		X			X				
Piptoporus betulinus									X				
Pleurotus ostreatus													X
Polyporus umbellatus					X	X	X						
Schizophyllum commune		X		X									
Trametes versicolor	X	X		X	X	X	X					X	

* Poisonous species, not edible.

FIGURE 57

Cortinarius caperatus (formerly known as *Rozites caperata*) the gypsy mushroom, is a choice edible that contains powerful antiviral compounds (Piraino and Brandt 1999). Widely distributed in temperate conifer forests, this mycorrhizal mushroom cannot be readily cultivated but often forms great colonies.

FIGURE 58

Mushroom mycelia exude droplets containing enzymes and antibiotics and profuse water. The enzymes digest lignin and cellulose, petroleum products, and many molecules held together by hydrogen-carbon bonds. The antibiotics stop microbial parasites. Mushrooms resist bacterial and fungal rot until they release spores, age, and die.

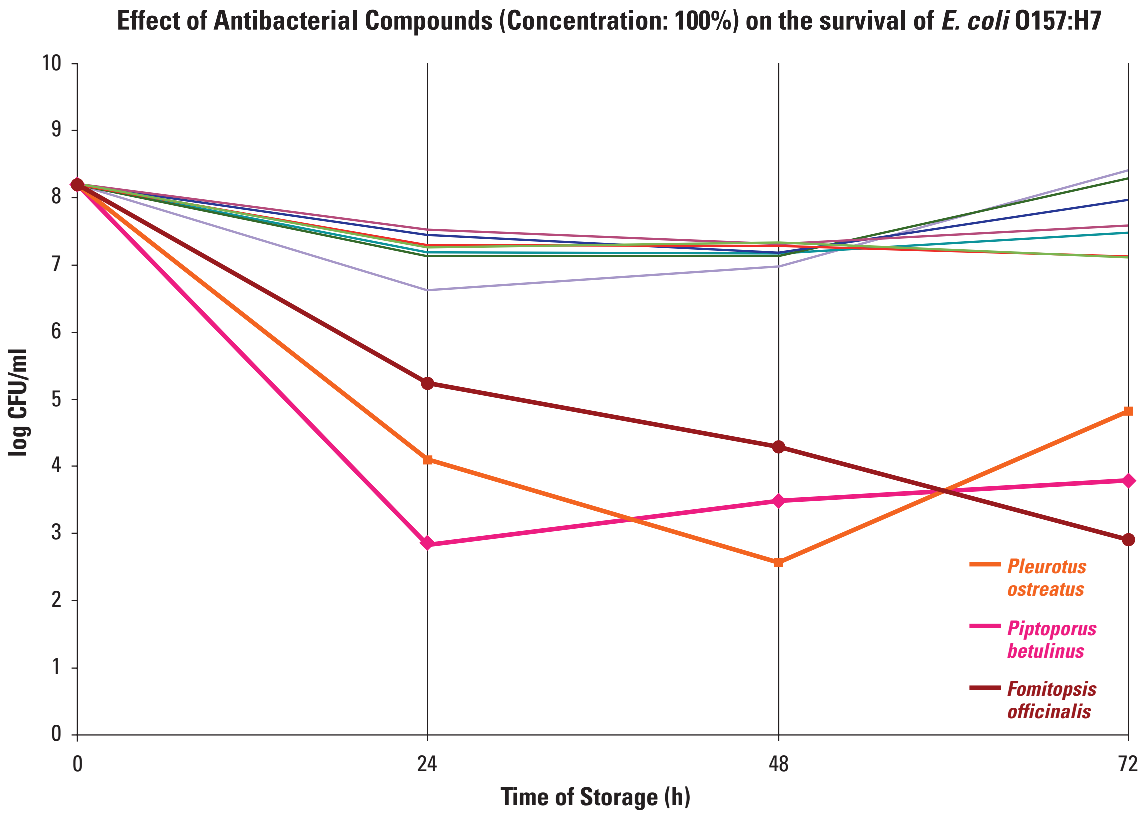


FIGURE G

This chart and the one on the following page show the antimicrobial activity of cold-water extracts created from washing exudates secreted from living mycelia from ten mushroom species. Vertical scale is log 10. With both *Escherichia coli* and *Staphylococcus aureus*, the number of colonies forming units (CFUs) per gram of water plummeted from more than 100,000,000 to the 1,000–10,000 CFU range in 48–72 hours, equivalent to more than 99.99% inhibition. The most antibacterially active species were an oyster mushroom (*Pleurotus ostreatus*), the birch polypore (*Piptoporus betulinus*), and agarikon (*Fomitopsis officinalis*).

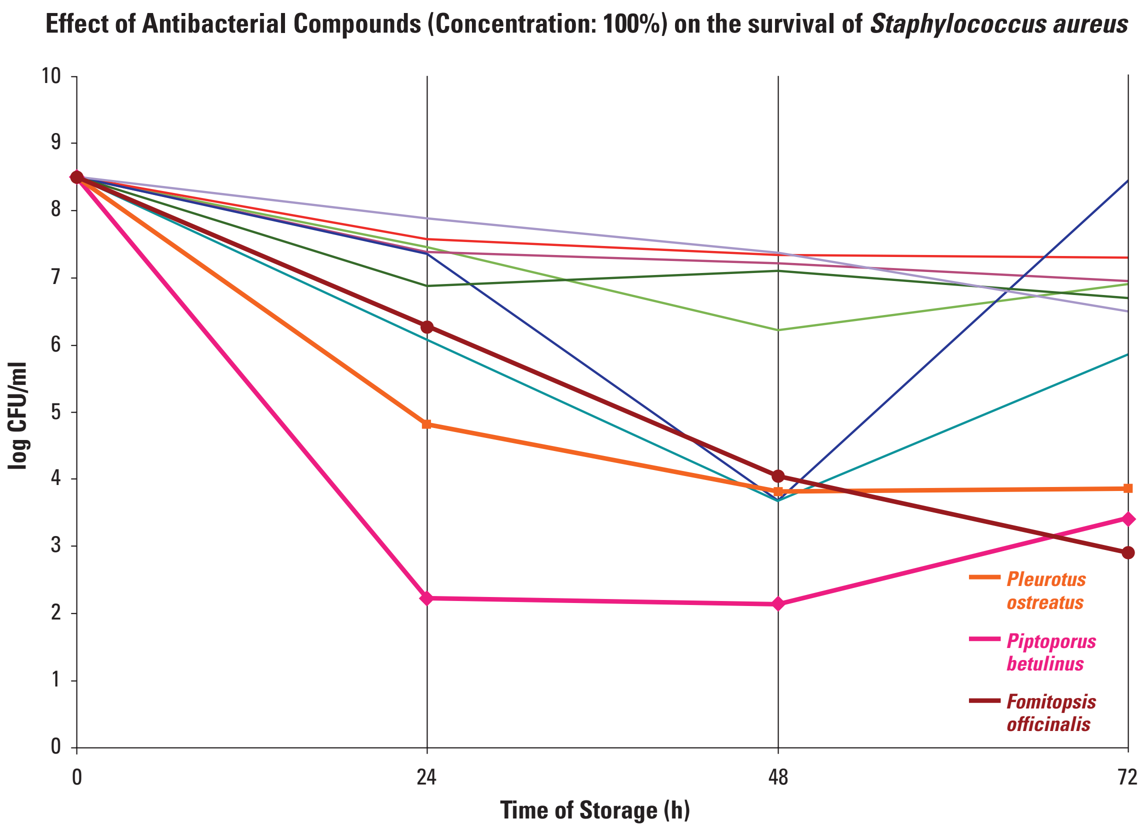


FIGURE H

See caption, previous page.

Mushrooms with Direct Antiviral Activity

Mushrooms are being actively explored by virologists for new sources of antiviral medicines.

	Hepatitis B	Herpes simplex I	Herpes simplex II	HIV	Influenza	Pox	Respiratory syncytial virus	Rous sarcoma virus	Tobacco mosaic virus	Varicella zoster	Vesicular stomatitis
Agrocybe aegerita									X		
Cordyceps sinensis	X										
Cortinarius caperatus (=*Rozites caperata*)		X	X				X	X		X	
Fomes fomentarius									X		
Fomitopsis officinalis				X		X					
Ganoderma lucidum		X	X	X	X						X
Grifola frondosa				X							
Inonotus obliquus				X	X						
Lentinula edodes		X		X	X						X
Piptoporus betulinus				X		X					
Pleurotus ostreatus				X							
Polyporus umbellatus	X										
Trametes versicolor				X							

FIGURE 59

A forest parasite, probably *Phaeolus schweinitzii,* fruiting from a stump, causes core rot. Note the band of white mycelium.

Mushrooms and Their Known Medicinal Agents

Mushroom	Common Name	Derived Medicine or Medicinal Properties
Agaricus campestris	Meadow mushroom	Campestrin, antibiotic
Amanita muscaria	Soma	Muscimol, ibotenic acid
*Amanita pantherina**	Panther cap	Muscimol, GABA-mimicking compound for neurological research
Calvatia gigantea or *Calvatia booniana*	Giant puffball	Calvacin, antibiotic
Clitocybe illudens	Jack-o'-lantern	Illuden-S, irofulven, anticancer, antibacterial
Coprinus comatus	Shaggy mane	Coprinol, antibiotic
Cordyceps subsessilis	Beetle Cordyceps	Cyclosporin, immunosuppressant
*Cortinarius caperatus**	Gypsy mushroom	Antiviral
Fomes fomentarius	Amadou	Antibacterial, fire-starting tinder
*Fomitopsis officinalis***	Agarikon	Antibacterial, antiviral, anti-inflammatory
Ganoderma applanatum	Artist conk	Antibacterial, anticancer
Ganoderma lucidum	Reishi	Triterpenoids, beta-glucans, anticancer, anti-inflammatory, ganomycin, antibiotic
Ganoderma tsugae	Hemlock reishi	Triterpenoids, beta-glucans, anticancer, anti-inflammatory, ganomycin
Grifola frondosa	Maitake	Anticancer (grifolan), antidiabetic
Piptoporus betulinus	Birch polypore	Betulinic acid, anticancer, antiviral
Pleurotus ostreatus	Oyster mushroom	Antiviral, anticancer (pleuran), cholesterol-lowering properties
Sparassis crispa	Cauliflower mushroom	Antibiotic (sparassol)
Trametes versicolor	Turkey tail	Anticancer, polysaccharide-K (PSK), polysaccharide-P (PSP), anticancer, corolin, antibiotic

* Mycorrhizal mushrooms that are difficult to cultivate.

** This species is on the Red List of nearly extinct species in Europe. Although still surviving in the Pacific Northwest of North America, its habitat is shrinking; as a result, widespread harvesting of this species is discouraged. Cultures can be obtained using cork borers without harvesting this rare species (see figure 53). I do, however, encourage the inoculation of trees with this species, especially wind-topped old-growth or mature second-growth Douglas firs.

FIGURE 60

Is this the largest organism in the world? This 2,400-acre site in eastern Oregon had a contiguous growth of mycelium before logging roads cut through it. Estimated at 1,665 football fields in size and 2,200 years old, this one fungus has killed the forest above it several times over, and in so doing it has built deeper soil layers that allow the growth of ever-larger stands of trees. Mushroom-forming forest fungi are unique in that their mycelial mats can achieve such massive proportions.

FIGURE 61

Along a trail up the Sol Duc River valley in the Olympic Peninsula rain forest, I came across this log fruiting honey mushrooms, probably in the *Armillaria ostoyae* group. Many logs and stumps sported this mushroom and smoky gilled woodlovers *(Hypholoma capnoides).*

FIGURE 62

The mycelium of the cauliflower mushroom *(Sparassis crispa),* overpowers the honey mushroom *(Armillaria ostoyae)* in culture. Similar dominance over *Armillaria* occurs with woodlovers like *Hypholoma capnoides,* and most notably turkey tails *(Trametes versicolor).* Although such observations from a petri dish test do not necessarily translate into the natural world, it is nevertheless a good indicator of competitiveness between species living in the same ecological niche. See also figure 288.

FIGURE 63

Azureus Stamets holding a cauliflower mushroom *(Sparassis crispa),* collected near Bagby Hot Springs, Oregon. This mushroom is often associated with very large old-growth trees and their stumps. In culture, it fights *Armillaria* root blight. See figure 62.

FIGURE 64

The smoky gilled woodlover *(Hypholoma capnoides)* is an edible mushroom, although not yet popular. This species, I believe, has many beneficial properties helping mycorestoration efforts.

FIGURE 65

A cauliflower mushroom *(Sparassis crispa)* fruiting from a coil of hemp rope. The mycoforester can lasso stumps with this myceliated rope, inoculating them, and help prevent the spread of devastating parasitic fungi like the honey mushroom *(Armillaria ostoyae).*

FIGURE 66

A delicious cauliflower mushroom *(Sparassis crispa),* a mild parasite, fruits at the base of an old-growth Douglas fir. This tree has given rise to annual fruitings of cauliflower mushrooms for two decades, perhaps longer.

FIGURE 67

Chicken of the woods *(Laetiporus conifericola),* is an edible polypore. When slices of this specimen were grilled on a barbecue, the flavor was just like white chicken meat. A non-parasitic but aggressive species, this group of mushrooms has species with interesting antimicrobial properties. I often find them in river valleys in the summertime. Being a brown rotter, this species plays a unique role in ecosystems infused with white rot fungi.

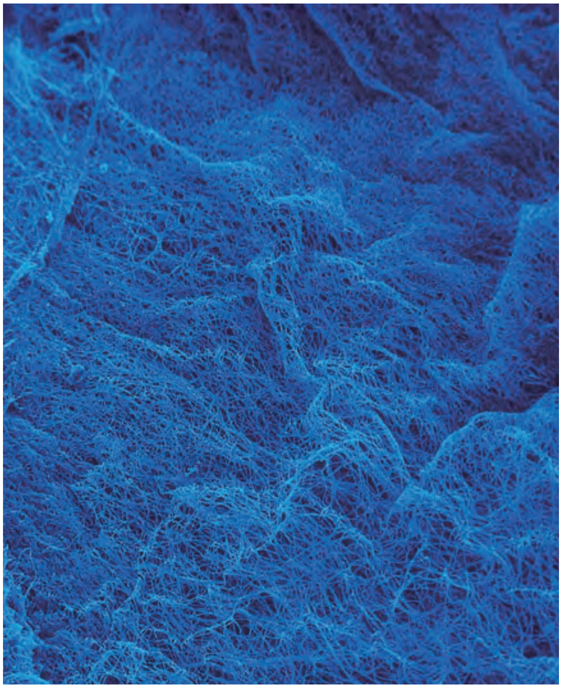


FIGURE 68

In this scanning electron micrograph of mushroom mycelium, these cells are about .5 to 2 microns thick. Chains of these cells can extend in length from a few microns to a few miles, forming an integrated, netted fabric of interconnected cells.

FIGURE 69

Skookum Inlet, where mycofiltration in the form of a patch of garden giant mushrooms, cleaned up flow of fecal coliform contaminants from my land.

FIGURE 70

Rhizomorphic mycelium of the garden giant *(Stropharia rugoso annulata)* tenaciously holds wood chips together. This mushroom thrives when it comes into to contact with bacteria, compared to its slow growth behavior under sterile, bacteria-free conditions in the laboratory. Until it makes contact with microbes, this species does not produce rhizomorphs.

FIGURE 71

Rhizomorph of a caerulescent *Psilocybe* grasping a cluster of dowels enveloped in a sheath of silky white rhizomorphs. The length of the pictured thread of mycelium weighed .002 grams and held dowels weighing 6.079 grams, meaning that this rhizomorph supported 3,029 times its mass. When 90 percent of this rhizomorph was cut away, it still supported the wooden dowels, meaning that it can hold more than 30,000 times its mass. This places into perspective how tenacious mycelial mats can be when they infuse habitats with their cellular networks. They grip a habitat and hold it tightly, stabilizing and protecting it from erosion.

FIGURE 72

This mycofiltration test chamber, sized to fit a bale of straw, myceliated or not, can be sectioned off, and samples of water can be taken both upstream and downstream.

Mushrooms versus Microbes

This chart describes mushroom species found to have specific antimicrobial effects on the corresponding microbes. Most microbes listed here are pathogens to both animals (humans) and mushrooms. (For a list of pathogenic fungi and their classification, see www.pfdb.net/myphp/database_eng.php. For a list of pathogenic bacteria and their classification, see www.bmb.leeds.ac.uk/mbiology/ug/ugteach/icu8/classification/head.html.)

	Aspergillus niger	*Bacillus* spp.	*Candida albicans*	*Escherichia coli*	*Listeria monocytogenes*	*Mycobacterium tuberculosis*	*Plasmodium falciparum*	*Pseudomonas aeruginosa*	*Pseudomonas fluorescens*	*Staphylococcus aureus*	*Streptococcus pneumoniae*	*Streptococcus pyogenes*
Agaricus brasiliensis				X								
Armillaria mellea		X								X		
Chlorophyllum rachodes										X		
Coprinus comatus	X	X	X	X				X		X		
Flammulina velutipes										X		
Fomes fomentarius				X				X				
Fomitopsis officinalis				X		X		X	X	X		
Ganoderma applanatum		X		X						X		
Ganoderma lucidum	X	X	X	X								
Grifola frondosa			X									
Hericium erinaceus	X	X	X									
Hypsizygus ulmarius										X		
Laetiporus sulphureus		X		X						X		
Lentinula edodes			X		X	X				X	X	X
Lepista nuda			X							X		
Macrolepiota procera										X		
Merulius incarnatus										X		
Piptoporus betulinus		X		X				X	X	X		
Pleurotus ostreatus	X	X		X			X	X	X	X		
Polyporus umbellatus				X			X			X		
Psilocybe semilanceata										X		
Schizophyllum commune			X	X						X		
Sparassis crispa		X										
Stropharia rugoso annulata				X								
Trametes versicolor	X		X	X						X	X	

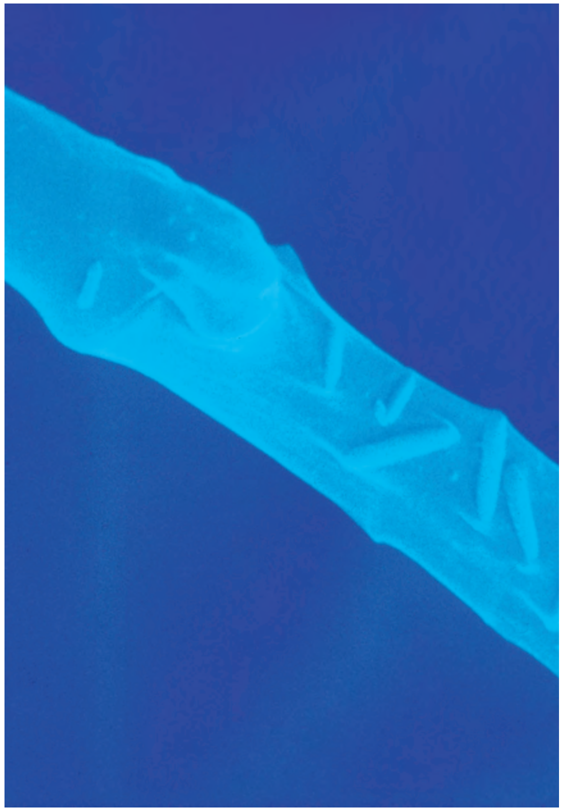


FIGURE 73

A scanning electron micrograph of mushroom mycelium carrying rods of *Bacillus subtilis,* a bacterium generally thought to be friendly to humans and mammals but antagonistic to many fungi. Also depicted is a clamp connection bridging 2 cells of mycelium.

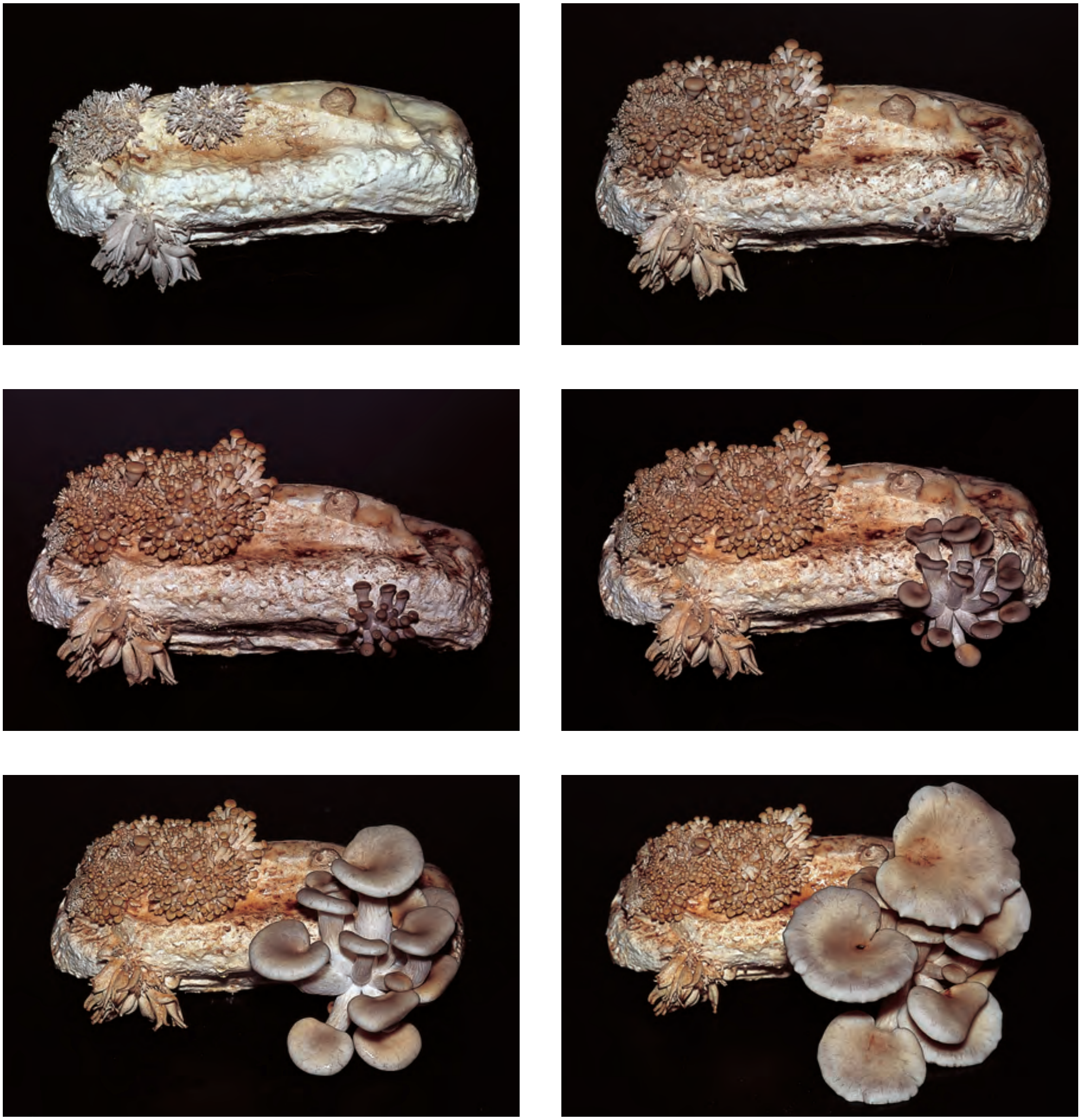


FIGURE 74

Daily time-lapse photos of oyster mushrooms fruiting from corncobs.

FIGURE 75

Several miles deep in the old-growth forest of the Hoh River valley of the Olympic National Forest, we encountered this tree scratched by a bear. Such wounds give birth to polypore mushrooms. Five years later, we returned to this tree, which had died, and had evidence of cubical brown rot. Presumably, the bear scratch was an entrance wound for infection from a brown rot fungus.

FIGURE 76

Piles of branches sit undecomposed after more than 20 years on a farm on the border of Mason and Thurston counties in Washington State. Had this wood been chipped, placed into contact with the ground, and/or shaded, saprophytic fungi would have flourished and the debris would have reentered the food chain.

FIGURE 77

When spored oil from a chain saw made contact with this slice of alder *(Alnus rubra)*, a mycelial colony of oyster mushrooms *(Pleurotus ostreatus)* soon developed. By using spored oils in chainsaws and chipping equipment, the decomposition process and therefore habitat recovery can be jump-started immediately upon cutting. Furthermore, by choosing an aggressive saprophytic mushroom species such as oysters, turkey tails, or woodlovers, parasitic fungi are confronted in a form of mycelial combat, thus lessening their resurgence.

FIGURE 78

Heart rot from a brown rot fungus, probably the velvet polypore *(Phaeolus schweinitzii)*. Such wood has low timber value and is usually left on-site, a motivation stated by some foresters to justify burning.

Some Notable Mycorrhizal Mushrooms and the Trees They Love

Nongourmet Mycorrhizal Mushrooms	Endomycorrhizae/ Ectomycorrhizae	Preferred Trees
Glomus intraradices	Endomycorrhizae	Cedars, redwoods
Pisolithus tinctorius	Ectomycorrhizae	Pines
Rhizopogon parksii	Endomycorrhizae	Deciduous

Gourmet Mycorrhizal Mushrooms	Endomycorrhizae/ Ectomycorrhizae	Preferred Trees
Boletus edulis and allies	Ectomycorrhizae	Pines
Cantharellus cibarius and allies	Ectomycorrhizae	Oaks, firs
Hydnum repandum	Ectomycorrhizae	Firs
Leccinum aurantiacum	Ectomycorrhizae	Pines
Tricholoma matsutake and allies	Ectomycorrhizae	Pines

FIGURE 79

On the Olympic Peninsula and elsewhere, the conventional practice after clear-cutting is to stack up the brush and burn it. First, the forest food chain must withstand the sudden loss of carbon and nutrients from cutting and removing the trees. Adding insult upon injury, the remaining brush is stacked and burned, further undermining the resident carbon return cycles. Is it any wonder our forest yields are in rapid decline, with thin soils and increased erosion after 3 generations of such practices?

FIGURE 80

An aerial view of our mycoforestry research site on Cortes Island, British Columbia. Having logging roads as ecological barriers bisecting the clear-cuts helped us set up comparative test plots with and without mycological enhancements. Approximately 50 percent of the brush and small-diameter trees left after logging were chipped and left on-site. Contrary to the site in figure 79, we didn't burn the brush, but chipped it so the debris could be recycled back into the land's food chain.

FIGURE 81

Two Douglas fir trees, one with and one without introduced mycorrhizae. Note the increase in root, shoot, and needle development.

FIGURE 82

Members of a volunteer bucket brigade place wood chips around half of the trees inoculated with mycorrhizae and half of the noninoculated trees.

FIGURE 83

Young Doulgas fir seedling without wood chips.

FIGURE 84

Young Douglas firs seedling collared with wood chips. The addition of wood chips cools the ground, increases moisture retention, and provides delayed-release nutrients as they decompose. Our experiment serves to prove how significant this practice is.

FIGURE 85

Arborists employed by many cities, including Seattle and Olympia, Washington, have instituted programs for placing wood chips from trimmings around trees for slow nutrient release.

FIGURE 86

A problem with monocropping. This planted third-growth forest is extremely dense with dead branches, hence fuel load, posing a significant fire danger.

FIGURE 87

Logging roads channel silt into valleys, such as occurs along this northern California hillside etched with zigzagging logging roads.

FIGURE 88

Depicted here is the conventional approach to reclaiming a road: digging deep ditches (called *tank traps* in military speak; I call them "terra interrupti") that block vehicles so that, ostensibly, the land can recover from human activity by disturbing it further.

FIGURE 89

Runoff saturated with silt flows directly into the Tahuya River, a salmon spawning ground.

FIGURE 90

Wood chips are dumped on the road surface.

FIGURE 91

Spreading straw over the wood chips that have been inoculated with oyster mushrooms.

FIGURE 92

David Sumerlin points to location where wood chips should be placed—up against the bank of the scar face of the road cut, thus eliminating erosion from the silt-producing exposed surface.

FIGURE 93

After 3 years, the reclaimed road showed a mantle of nearly contiguous mycelia at the point where wood chips and gravel meet, binding together the otherwise loose subterrain. Note that the upturned rock had rested upon a mantle of mycelium underneath it. My hypothesis is that the mycelium became resident in this subterranean zone, feeding upon the soupy, nutrified water that flows from above.

FIGURE 95

After 3 weeks, oyster mushrooms fruit from the tub. As the oil-soaked straw is metabolized by the mycelium, it lightens in color, a direct reflection of the reduction of petroleum hydrocarbons. The large size of the mushrooms shows that the mycelium is undeterred and is digesting the oil as a nutrient.

FIGURE 94

In this version of a mycelial mat, 10 ml of car gearbox oil was poured onto 2 pounds of oyster mushroom mycelium that had colonized straw.

FIGURE 96

Two white rot polypore mushrooms, turkey tails *(Trametes versicolor)* and artist conks *(Ganoderma applanatum)*, co-inhabiting the same alder *(Alnus rubra)* stump.

FIGURE 97

The remnants of a tree speak to the history of its fungal occupants. Here a brown rot fungus, causing cubical cracking of the remaining lignin, exists beside a white rot fungus that leaves the pithy cellulose behind.

Mushrooms and Their Habitats

	Grassland	Manured Soils	Grass & Leaf Litter	Wood Chips	Logs, Stumps & Snags	Brown (B) or White (W) Rot?
Agaricus bernardii	X	X				W
Agaricus brasiliensis	X	X				W
Agrocybe aegerita				X	X	W
Chlorophyllum rachodes			X			W
Coprinus comatus	X	X	X			W
Flammulina velutipes				X	X	W
Fomes fomentarius					X	W
Fomitopsis pinicola					X	B
Ganoderma applanatum					X	W
Ganoderma lucidum					X	W
Grifola frondosa					X	W
Hericium abietis					X	W
Hericium erinaceus					X	W
Hypholoma capnoides				X	X	W
Hypholoma sublatertium				X	X	W
Hypsizygus ulmarius					X	B
Inonotus obliquus					X	W
Laetiporus sulphureus & allies					X	B
Lentinula edodes					X	W
Macrolepiota procera	X	X	X			W
Morchella angusticeps				X		B?
Pholiota nameko				X	X	W
Piptoporus betulinus					X	B
Pleurotus ostreatus				X	X	W
Psilocybe cubensis		X	X			W
Psilocybe cyanescens & allies			X	X	X	W
Sparassis crispa					X	B
Stropharia rugoso-annulata			X	X		W
Trametes versicolor				X	X	W

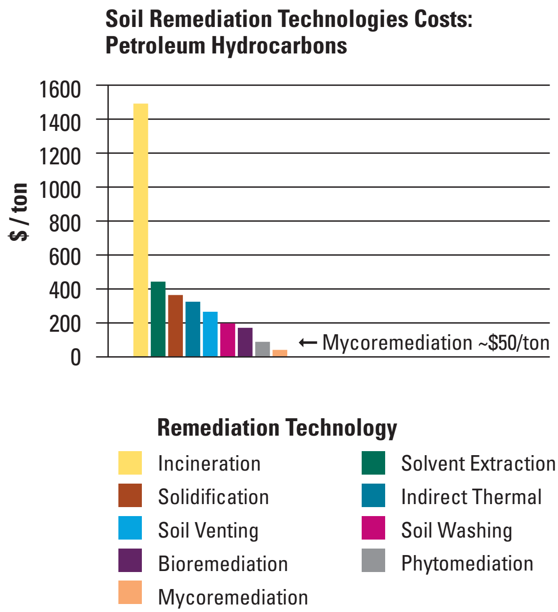


FIGURE 98

Cost comparison of remediation methods of polycyclic aromatic hydrocarbons.

FIGURE 99

Rhizomorphic mycelium running on cardboard channels water to moisten its habitat in advance of contact. Throughout nature, mycelia act as an active hydrological transport system. The mycelia increase the moisture retention ability of the habitats they colonize through secretions of water and sugars from the advancing, fingerlike hyphal tips.

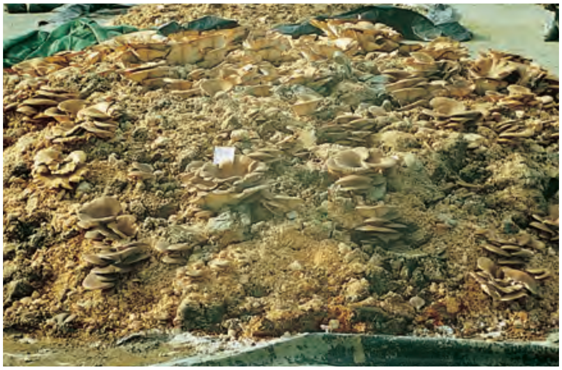


FIGURE 100

A pile of diesel-contaminated soil under attack by oyster mushrooms.

FIGURE 101

Some of the mushrooms reached mammoth sizes, a testimonial to the nutrition they found in the petrochemicals.

FIGURE 102

Near the end of the trial, as the mushrooms rotted away, plants appeared. Our pile regreened, becoming an oasis of life, while the other piles remained lifeless.

FIGURE 103

Oyster mushroom primordia fruiting from human hair. Since hair naturally soaks up petroleum, it can be used to absorb oil floating in water and then be saprophytized by mycelium.

Toxins, Their Primary Origins and Research Showing Efficacy of Their Fungal Degradation

Type of Toxin	Products or Processes That Emit Toxins	Supporting Research References
Anthracenes	Dyes, pesticides, and derivatives: benzo(a)pyrenes, wood preservatives, fluorene, naphthalene, acenaphthene, acenaphthylene, pyrenes, biphenylene	Johannes et al. 1996; Knapp et al. 2001
Anthraquinones	Dyes	Kasinath et al. 2003; Minussi et al. 2001; Novotny et al. 2001, 2003; Hatvani and Mecs 2003
Benzopyrenes (PAHs)	Incinerators	Qiu and McFarland 1991
Chlorinated aromatic compounds: pentachlorophenol (PCP), trichlorophenol (TCP), polychlorinated biphenyls (PCBs), dioxins, chlorobenzenes	Transformers, lighting fixtures, paper products, chlorine bleaching, paints and coatings	Gadd 2001
Copper/chromium	Treated wood	Humar et al. 2004; Illman et al. 2003
Dimethyl methylphosphonates (DMMP)	Chemical warfare agents: VX, sarin, soman	Thomas et al. 1999; Word et al. 1997
Dioxins	Incineration of industrial wastes, forest fires/wood burning, coal-fired plants	Chiu et al. 1998
Pentachlorophenol	Pesticides, preservatives	Kondo et al. 2003
Pesticides	Alachlor, aldrin, chlordane, DDT, heptachlor, lindane, mirex, atrazine, benomyl	Gadd 2004
Petroleum hydrocarbons	Oil, coal, tar, gasoline, diesel	Bhatt et al. 2002; Cajthaml et al. 2002; Eggen and Sasek 2002; Sasek 2003; Thomas et al. 1999; Moder et al. 2002

Mushrooms with Activity against Chemical Toxins

More species and toxins will be added over time. Several of the species probably act upon more toxins than the ones listed above. I will update this chart on www.fungi.com as more research is published.

	Anthracenes	Benzopyrenes	Chromated Copper Arsenate	Chlorine	Dimethyl methyl phosphonate (VX, Soman, Sarin)	Dioxin	Persistent Organophosphates	Polycyclic Aromatic Hydrocarbons (PAHs)	Polychlorinated Biphenyls (PCBs)	Pentachlorophenols (PENTAs)	Trinitrotoluene (TNT)	Brown (B) or White (W) Rot?
Antrodia radiculosa			X							X		B
Armillaria ostoyae					X							W
Bjerkandera adusta		X						X				W
Gloeophyllum trabeum			X			X						B
Grifola frondosa									X			W
Irpex lacteus								X				W
Lentinula edodes								X	X	X		W
Meruliporia incrassata			X							X		B
Mycena alcalina				X								?
Naematoloma frowardii (=Hypholoma)								X			X	W
Phanerochaete chrysosporium		X								X	X	W
Pleurotus eryngii						X						W
Pleurotus ostreatus		X			X	X		X	X		X	W
Pleurotus pulmonarius						X					X	W
Psilocybe spp.					X		X					W
Serpula lacrymans			X					X				B
Trametes hirsuta										X		W
Trametes versicolor	X		X		X	X	X			X	X	W

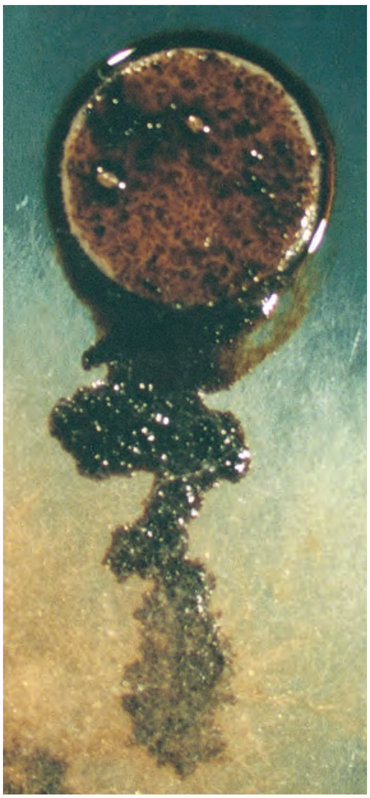


FIGURE 104

Cellulose plug saturated with bunker C crude oil absorbed by oyster mushroom mycelium. The mycelium darkens with absorption, metabolizes the oil, and becomes white again after digestion.

FIGURE 105

A bag of glowing *Mycena chlorophos* mycelium.

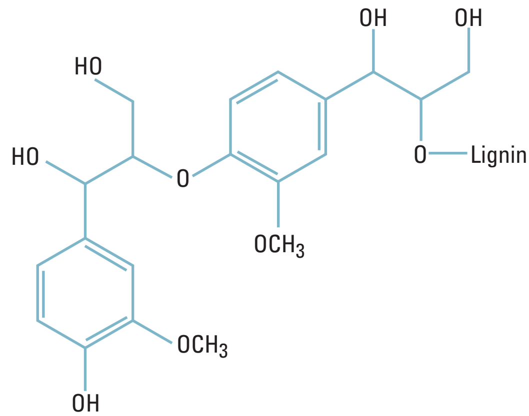


FIGURE 106

Molecular structure of lignin.

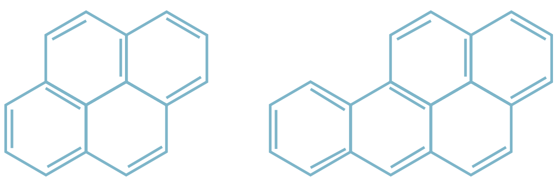


FIGURE 107

Molecular structure of polycyclic aromatic hydrocarbons.

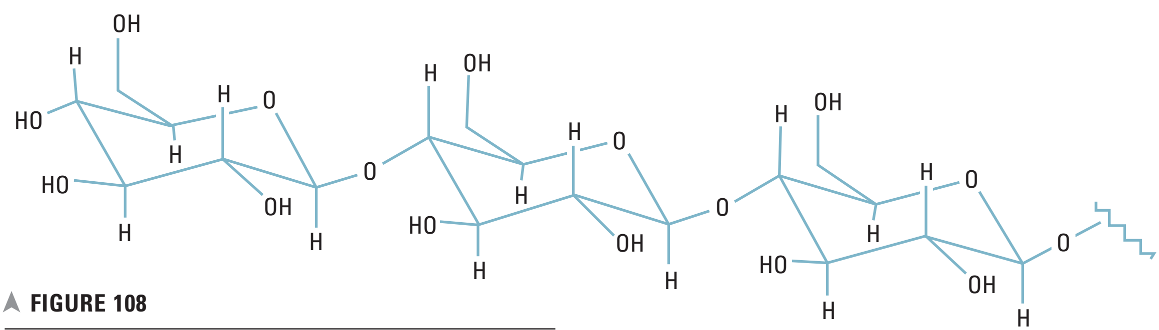
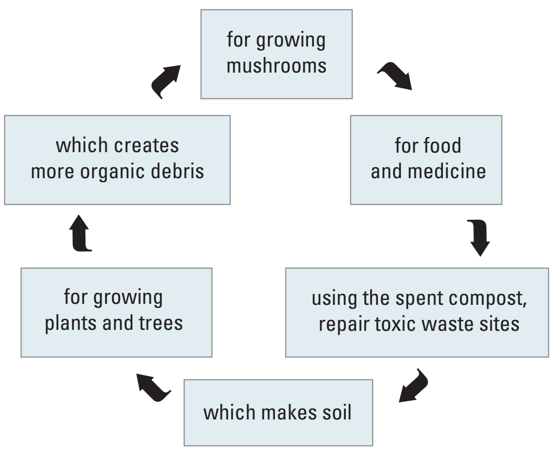


FIGURE 108

Molecular structure of cellulose.



for growing mushrooms
for food and medicine
using the spent compost, repair toxic waste sites
which makes soil
for growing plants and trees
which creates more organic debris

Mushrooms versus Heavy Metals

This chart gives a general, preliminary guide to the bioaccumulation coefficients—concentration factors—of a mushroom species' ability to upchannel heavy metals from its myceliated habitat. This chart is a work in progress. Please consult the scientific literature cited in the text for more information.

	Arsenic	Cadmium	Radioactive Cesium	Lead	Mercury	Copper
Agaricus arvensis		X			150X	
Agaricus bisporus		X			X	
Agaricus bitorquis		X		23X	165X	
Agaricus brasiliensis		X			X	
Agaricus brunnescens	X	X			X	
Agaricus campestris		X		10X	10X	
Amanita muscaria		X			X	
Amanita rubescens		X				
Boletus badius			X			
Boletus edulis		10X	X	X	250X	X
Cantharellus cibarius			2X			
Cantharellus tubaeformis (*Craterellus tubaeformis*)			X			
Chlorophyllum rachodes	X			X	X	X
Clitocybe inversa	X	X				
Coprinus comatus	21X	8X			27X	
Coprinus spp.		X				
Flammulina velutipes	X					
Gomphidius glutinosus			10000X			
Laccaria amethystina	X		X			
Lactarius helvus			X			
Lactarius turpis			X			
Leccinum scabrum			X		X	
Lepista nebularis	X					
Lepista nuda					100+X	X
Lycoperdon perlatum			X	2X	100X	X
Marasmius oreades					X	
Macrolepiota procera					230X	
Morchella spp.				70–100X		
Morchella atretomentosa				X	X	
Paxillus atrotomentosus			1180X			
Pleurotus ostreatus		X			65–140X	
Pleurotus pulmonarius		X			X	X
Rozites caperata			X			
Suillus tomentosus				67X	6X	
Trametes versicolor					X	
Tricholoma magnivelare	22X					

FIGURE 109

In this mycelial mat the elm oyster mushroom *(Hypsizygus ulmarius)*, a brown rot fungus, fruits among grasses that feed on decomposing coconut fiber. Such mycelial mats can be used not only to absorb a toxic spill but as a pedestal for mycelial growth leading to ecological recovery. Mycoremediators can use toxin-specific mycomats to carpet a toxin-laden landscape in a dual attempt to destroy the underlying toxins and to give rise to customized descendant plant communities. Mycelium leads the way to habitat restoration. Bacteria, plants, and animals follow, fueling the food chain with nutrients and renewing life cycles.

FIGURE 110

Gomphidius glutinosus, a mycorrhizal mushroom, can concentrate radioactive cesium-137 to more than 10,000 times the background level.

Contaminated Habitat Scenarios, Their Toxins, and the Mushrooms That May Heal Them

Contaminated Habitat Scenario	Recommended mushrooms
Petroleum products (oil, diesel, gasoline, petrochemicals)	*Pleurotus ostreatus*
Chemical dyes	*Ganoderma* and *Trametes* species
Industrial metals (lead, cadmium, arsenic, mercury, selenium, radioactive cesium-137 and cesium-134)	Large *Agaricus, Lepiota,* and mycorrhizal species
Munitions (TNT)	*Hypholoma* and *Flammulinas* species
Organophosphates, chemical weapons (VX, sarin)	Polypores, oysters, and *Psilocybe* species
Biologicals (*Escherichia coli, Bacillus* sp.)	*Calvatia gigantea, Coprinus comatus, Fomes fomentarius, Ganoderma* species, *Piptoporus betulinus, Pleurotus* species, *Polyporus umbellatus,* and *Stropharia rugoso annulata*
Nitrates and phosphorus-bound toxins	*Agaricus bernardii, Agaricus silvicola* and allies, *Coprinus comatus,* and *Psilocybe* species

FIGURE 111

Dusty Yao inspects an aerial termite nest attached to a palm tree in the Bahamas. From these nests, termites march far and wide, consuming wooden structures.

FIGURE 112

Our house was destroyed: first by fungus; then by carpenter ants; and then by humans with the help of this machine. The ants followed the path of mycelium and pulverized this house. The author, desperate for a solution, tried something new and received a patent for the idea in 2003: U.S. Patent 6,660,290.

FIGURE 113

Mycelium emerging from a carpenter ant, *Camponotus modoc.* This ant ingested the pre-sporulating mycelium and became mummified. The infection here came from within.

FIGURE 114

Cordyceps myrmecophilia mushroom fruiting from the carcass of carpenter ants of the genus *Camponotus.* Some species of *Cordyceps* can express a mold state such as in the green mold, *Metarhizium anisopliae,* which produces spores highly pathogenic to ants, termites, locusts, mosquitos, and mites.

FIGURE 115

Cordyceps lloydii fruiting from a carpenter ant *(Camponotus* sp.) in Costa Rica. The ant, once infected, has the irresistible impulse to climb to the top of the jungle canopy. Once it has ascended and locks its mandible into a leaf, it dies, whereupon a mushroom sprouts from its carcass. This behavior ensures that the spores of the mushroom will be spread far and wide by the winds.

FIGURE 116

The *Cordyceps-Metarhizium* life cycle.

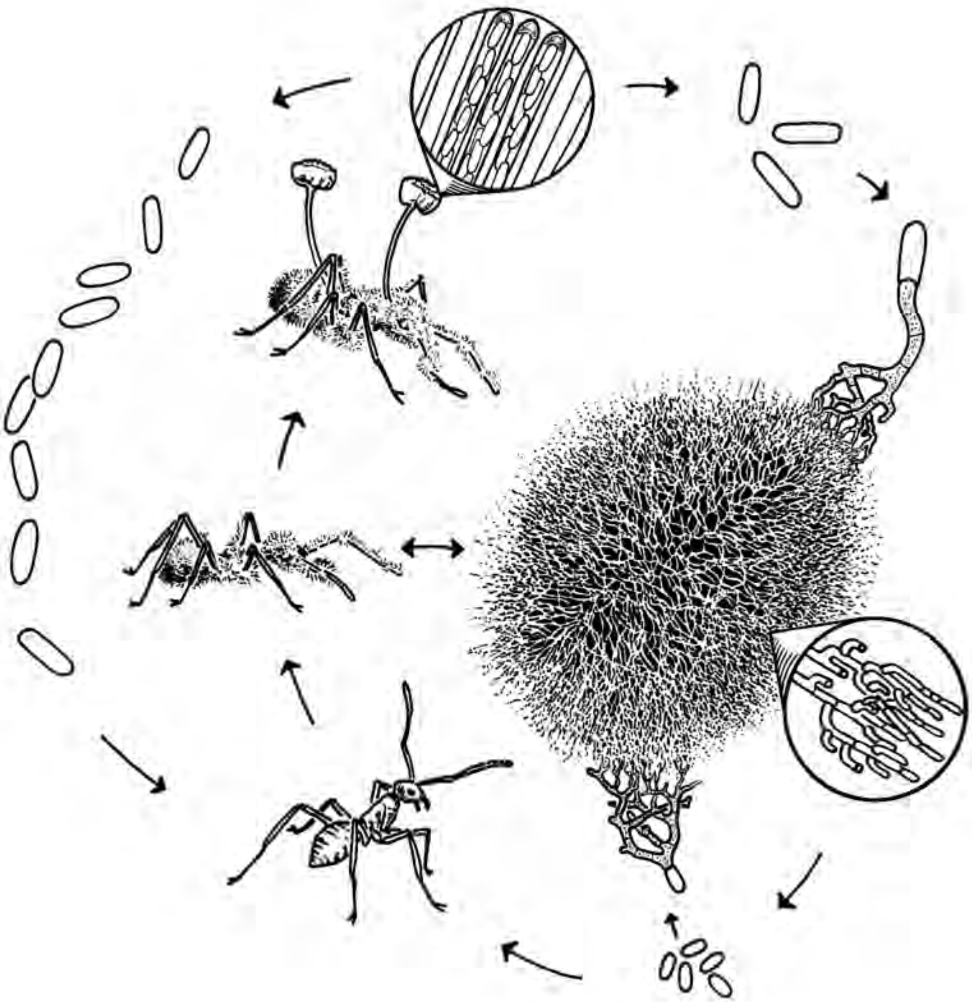


FIGURE 117

This strain of *Metarhizium anisopliae* shows the emergence of a white wedge sector, which when subcultured, leads to strains that are delayed in sporulation. The resultant presporulating mycelium attracts many species of pest insects that unsuspectingly consume and spread the infection.

FIGURE 118

After subculturing, the mycelium enters into a presporulating state from its parental green mold form, opening up reservoirs of enticing feeding stimulants and attractants to ants and termites. These two culture dishes are in fact the same strain. With many cultures, the white forms peter out as they are subcultured over time.

FIGURE 119

Ants swarming on presporulating mycelium of an entomopathogenic fungus. After contact, the ants become infected and spread the mycelium which subsequently regrows, resulting in their death.

FIGURE 120

Here, when an extract of a presporulating entomopathogenic mycelium grown on rice is placed onto cellulose, termites tunnel to it, ignoring three nontreated controls.

FIGURE 121

The birch polypore *(Piptoporus betulinus)* growing on birch in Germany. This species is a potent medicinal mushroom.

FIGURE 122

Mushroom spore prints on a hat, when you wear it you'll trail invisible spores behind you like fairy dust. From these spore trails mushrooms can emerge long after the traveler has moved on. Mushrooms use us as vehicles for transporting and dispersing spores.

FIGURE 123

Clothing is also a good fabric to make spore prints on. Such "mushroom wear" is increasing fashionable amongst a group of West Coast mycophiles.

FIGURE 124

These hats, being used as temporary vessels for carrying mushrooms (in this case *Psilocybe azurescens*) are impregnated with billions of spores, allowing for the spread of this species as far and wide as the wearer travels.

FIGURE 125

Spore printing *Agaricus brasiliensis,* the almond portobello, on paper. Note the spore trails, which follow air currents.

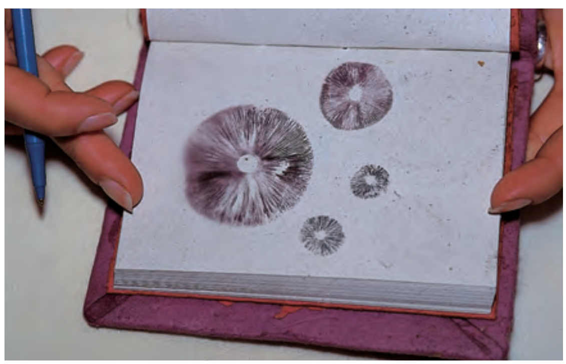


FIGURE 126

Spore prints can be made in a journal when traveling.

FIGURE 127

Spore printing is fun!

FIGURE 128

Making spore prints of the parasol mushroom *(Chlorophyllum rachodes)* on clean glass.

FIGURE 129

These two jars contain spores. One is full of reishi *(Ganoderma lucidum)* and the other has a mixture of maitake *(Grifola frondosa),* shiitake *(Lentinula edodes),* oysters *(Pleurotus ostreatus),* nameko *(Pholiota nameko),* and pioppinos *(Agrocybe aegerita)* collected from the plastic ductwork in a growing room every few months. The more than 2 pounds of spores depicted here are roughly equivalent to 1,000,000,000,000 (1 trillion!) spores—enough to inoculate tens of thousands of stumps! This is an undervalued product most mushroom farmers discard, not realizing its utility.

FIGURE 130

One of these spored oils was made especially for Ken Kesey and the Merry Pranksters and contains hundreds of millions of spores of *Psilocybe azurescens.* See also figure 77, showing a mycelial colony emanating from point of contact with spored oil.

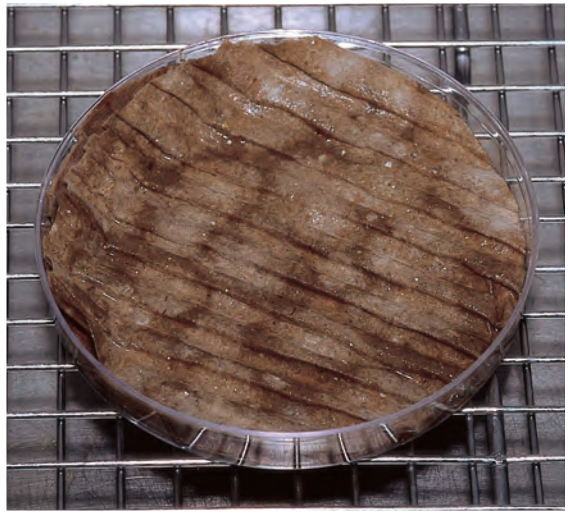


FIGURE 131

Mushroom spores germinating on corrugated cardboard. In this case, the cardboard was exposed to the mushroom for a few hours and then covered. A week later, island colonies of germinating spores appeared.

FIGURE 132

Two bags of commercial spawn: the yellowish one is maitake *(Grifola frondosa)* sawdust spawn; the other is shiitake *(Lentinula edodes)* grain spawn.

FIGURE 133

We inoculated these wood chips the year before and created a mycelial lens. We use this as a mother patch and transplant mycelium from it to other locations.

FIGURE 134

Scraping away the surface chips, we usually discover islands of mycelium which are then scooped up and transplanted. (By disturbing the wood chips in the mother patch, its mycelium is spurred into vigorous regrowth.) Usually a concentration of inoculation from 1:20 to 1:4 works best. A 1:20 inoculation rate means that 1 gallon of naturalized mycelium can inoculate 20 gallons of substrate, in this case more wood chips. Each year the new descendant patches can be amplified at a similar rate. In a few years, the amount of mycomass that can be generated is impressive: one 4 by 4-foot patch can be expanded to over 128,000 square feet, over 3 acres, in 3 years. But, to be successful, you must learn how to run with mycelium.

FIGURE 135

When selecting natural spawn from a wild mushroom patch, choose mycelium that tenaciously grips the wood chips. One test for vigor of the mycelium is whether or not the rhizomorphs can suspend the chips in the air.

FIGURE 136

Before the invention of pure culture spawn, Japanese shiitake growers collected logs from the woods and then used the "soak and strike" method, which means to immerse the logs in water and then violently hit them to induce fruiting. By interspersing newly cut logs among the fruiting logs (see background), the growers encouraged the spores from the shiitake mushrooms to inoculate the neighboring logs.

FIGURE 137

Turkey tail fruiting from a log inoculated with pure culture shiitake spawn. The wild turkey tail got there first and prevailed. In this case, the competing fungus is also a beneficial medicinal.

FIGURE 138

A successful transplantation strategy: taking a mycelium-covered fragment of wood and placing it onto wet cardboard. This method is one way to create natural spawn. Note the forking of the mycelium as it runs.

FIGURE 139

You can use an outdoor master patch to make several contact mycelial prints by periodically replacing the colonized corrugated cardboard atop the mushroom bed over the course of a year. Each one of these myceliated sheets can be used as a faceprint, laid upon wood chips, or used as a footprint with wood chips placed upon it. Or, the myceliated cardboard can be sandwiched between burlap bags filled with wood chips to make burlap bag spawn. (The patch featured here was originally grown from dowel spawn inoculated with stem butts. See figures 152 to 156.)

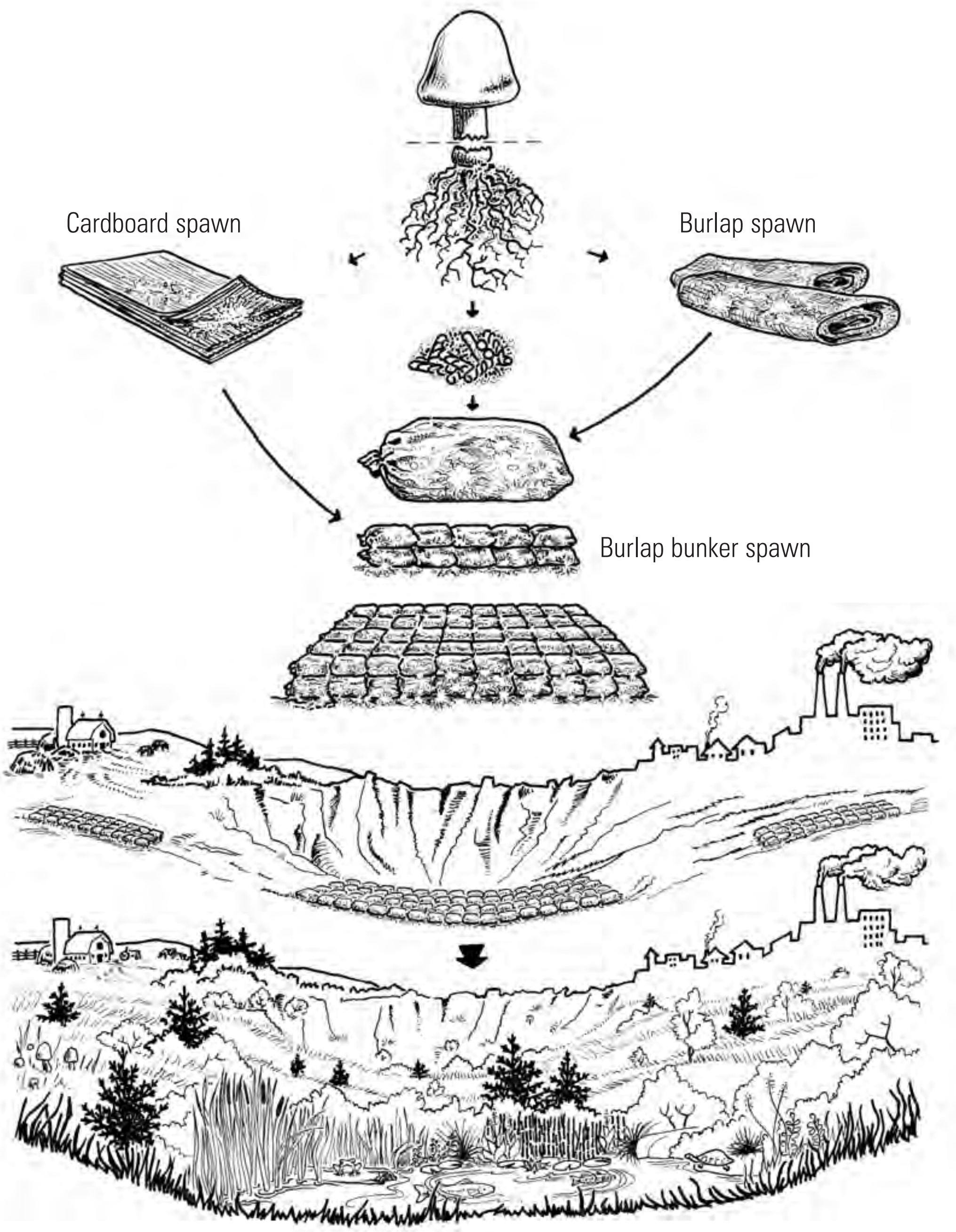


FIGURE 140

Overview of using stem butts to generate mycelium for mycorestoration.

FIGURE 141

First, gather fresh mushrooms, moist corrugated cardboard, and an incubation container.

FIGURE 142

This fluffy stem base regrows with vigor after being cut.

FIGURE 143

Cut the stem butt from the mushroom.

FIGURE 144

Place the stem butt pieces onto the moist cardboard and fold.

FIGURE 145

Three weeks later, mycelium surges from the cut stem butt and is well on its way to creating cardboard spawn.

FIGURE 146

Dusty Yao plucks a garden giant *(Stropharia rugoso annulata)* from her garden, being careful to keep the stem butt and its nurturing rhizomorphs intact.

FIGURE 147

Rhizomorphs attached to the stem butt can regrow—if handled carefully. Be especially careful that they don't dry out before use.

FIGURE 148

Cutting the stem butt from the mushroom.

FIGURE 149

Placing cut stem butts, with rhizomorphs attached, into moistened, folded, or sandwiched corrugated cardboard. This folded cardboard, once inoculated, is placed into a cardboard box or plastic tub with a loose lid and drainage holes, and incubated outdoors in the shade and on the ground.

FIGURE 150

Regrowth after 4 days.

FIGURE 151

After a month, the mycelial colonies from each portion of the cut stem butts merge to form a contiguous colony. This cardboard can now be used as spawn for inoculating more wood chips by placing it mycelial face down onto wood chips or putting several inches of wood chips on top of it to make a mycelial footprint. Alternatively, this sheet of myceliated cardboard spawn can be sandwiched between two moist straw bales, burlap sacks filled with wood chips, or more cardboard. Like all spawn, its life span is limited: move it or lose it. Mycelium of many mushroom species can be grown in a similar fashion.

FIGURE 152

Stem butts are placed into 20 pounds of soaked birch dowels (10,000), pushed just beneath the surface.

FIGURE 153

A layer of cardboard is placed on top of the stem butt–inoculated dowels. Alternatively, a woven mat (coconut fiber, hemp, bamboo, etc.) can be used.

FIGURE 154

The cardboard box holding 20,000 dowels, now inoculated with a few stem butts, is left outside to cold incubate through the winter and spring. The cardboard incubation box is soaked by natural rainfall and exposed to freezing temperatures, but recovers. Only mushroom species native to freezing ecosystems survive overwintering. The breathability of the cardboard box helps the mycelium grow.

FIGURE 155

Half the dowels have been colonized 6 months later. Large islands of mycelium can be harvested. Many of the nonharvested loose dowels are mixed through the remaining dowels, which, a month later, are also covered with whitish rhizomorphic mycelia. Once mycelium is at this stage, this box of "mother spawn" is explosive in its growth potential and can pump out waves of mycelium if you repeatedly harvest mycelial islands and then replenish with more dowels.

FIGURE 156

Ethan Schaffer enjoys the scent from plug spawn made from stem butts.

FIGURE 157

A dowel laced with whitish rhizomorphs. Each dowel becomes a platform for projecting rhizomorphs. The mycelium on this single dowel could potentially remediate many acres of polluted land. When mycelial colonies springing forth from the dowels touch, they share nutrition and grow stronger.

FIGURE 158

On March 20, myceliated dowels were spread over wood chips and then covered with another layer of fresh wood chips 1 to 2 inches deep.

FIGURE 159

On November 9, mushrooms appeared.

Species Known to Regrow from Stem Butts

Genus/species	Common name
Agaricus augustus	Prince
Agaricus brasiliensis	Brazilian blazei, himematsutake
Agaricus subrufescens	Almond mushroom
Agrocybe aegerita	Pioppinno
Agrocybe species	Ground dwellers
Chlorophyllum rachodes	Shaggy parasol
Hypholoma capnoides	Clustered woodlover
Hypholoma sublatertium	Kuritake or brick top
Macrolepiota procera	Parasol
Morchella angusticeps	Black morel
Morchella esculenta	True morel
Morchella species	Morels
Pholiota nameko	Nameko
Pholiota species	Scaly caps
Pleurotus ostreatus	Oyster
Pleurotus pulmonarius	Phoenix oyster
Psilocybe azurescens	A-z's
Psilocybe cubensis	San Isidros, cubies
Psilocybe cyanescens	Wavy caps
Psilocybe cyanofibrillosa	Cyclone psilocybe
Psilocybe subaeruginosa	Australian psilocybe
Sparassis crispa	Cauliflower
Stropharia rugoso annulata	Garden giant or king Stropharia
Stropharia species	Swordbelt mushrooms
Trametes versicolor	Turkey tail or yun zhi

FIGURE 160

A handful of plug spawn made from stem butts (see figure 152) inoculates untreated wood chips in a burlap sack.

FIGURE 161

Incubation of inoculated burlap bags filled with wood chips, which I call "bunker spawn."

FIGURE 162

Mycelium penetrates the burlap, which decolorizes as it's decomposed.

FIGURE 163

Sometimes, the best growth occurs where the burlap bags make contact with native soil.

FIGURE 164

This bag was inoculated with oyster mushroom mycelium and then submerged in a waterway to capture bacteria from a pond. Upon retrieval, oyster mushrooms popped out.

FIGURE I

To reduce coliform bacteria from an upland farm, two rows of woodchip-filled burlap sacks, inoculated with oyster mushroom mycelium, catch surface water before entering a sensitive salt-water estuary in Mason County, Washington, USA. Rows of myceliated bags are added annually as a best management practice. I prefer using woodchips from storm-created debris and inoculating with a native mushroom with proven antimicrobial properties. Similarly, such an arrangement can be used to catch and destroy chemical effluents.

FIGURE 165

Another application I favor is using myceliated burlap sacks as an ecosphere for habitat restoration. Not only does this "mycopod" catch silt, trap bacteria, and encourage insects and worms, it also acts like a nurse log to help a Douglas fir seedling get started. The grass soon climaxes, dies, and further fuels the fungal carbon life cycle. After two years, the burlap sack disintegrates. Complex communities can be created, customized to each particular location and needs.

FIGURE 166

Pure cultured dowel or plug spawn.

FIGURE 167

Aggressive leap-off of mycelium from acclimated, natural-culture dowel spawn of *Psilocybe cyanescens* onto crude, raw, contaminated, dirty, nasty, untreated wood debris. The ability of naturalized mycelium to project from wooden dowels and compete is impressive compared to that from dowels inoculated with pure culture mycelium, which often dies or is eaten upon contact with this same material. Pure culture spawn, if not immediately parasitized, slowly adapts its immune system to newly contacted microbial populations, eventually naturalizing to the resident microflora and then rebounding with spurts of growth.

FIGURE 168

A habitat is reborn. David Sumerlin stands in a planted grove of poplars rapidly growing from a forest floor built of burlap sacks filled with wood chips permeated by *Psilocybe cyanescens* mycelium. Bags of wood chips were placed on clay-mineral earth around transplanted trees. Leaf and twig fall fuels the carbon cycle: as trees grow, mycelium thrives, soils thicken, and mushrooms form. From what was once barren soil, a whole ecosystem flourishes in about 5 years.

FIGURE 169

La Dena Stamets holding oyster mushrooms fruiting from a bag of trimmings of U.S. paper currency, which is made from hemp and cotton. (You can make money growing mushrooms on money!) The U.S. Treasury trucks its paper-money trimmings to recycling centers. Nearly 2 pounds of oyster mushrooms fruited from this 6-pound bag of trimmings—the most efficient yield I have seen from a first flush.

FIGURE 170

Using a food-grade steel drum and crab-pot burner for hot-water or steam pasteurization of straw.

FIGURE 171

A specially designed stainless steel pasteurization chamber. Steam is injected through a port on the side. Once pasteurization is complete, the door is lowered and doubles as a ramp for unloading the straw.

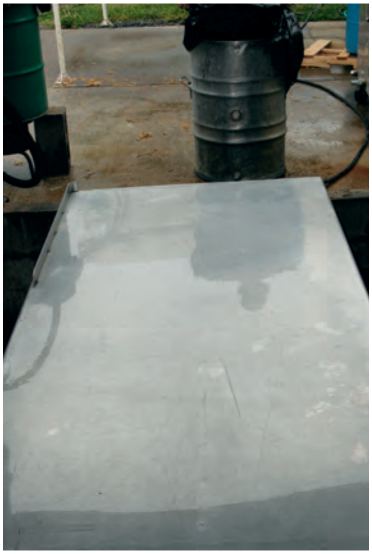


FIGURE 172

A cleaned table is an ideal surface for inoculating straw.

FIGURE 173

Using a pitchfork, straw is tossed onto the clean table.

FIGURE 174

Once the straw is cool, pure grain spawn is laid on top and then evenly mixed through. Approximately 8 pounds of grain spawn can make 20 to 40 bags (kits) weighing 6 to 8 pounds each. Each kit produces 1 to 2 pounds of fresh mushrooms 2 to 8 weeks after spawning.

FIGURE 175

Damein Pack packs inoculated straw into bags.

FIGURE 176

Once filled and closed using a twist tie, the bags are punctured using bladeless arrowheads mounted on a board.

FIGURE 177

Dusty Yao holds the phoenix oyster mushroom *(Pleurotus pulmonarius)* fruiting from pasteurized straw 2 weeks after inoculation with grain spawn.

FIGURE 178

La Dena Stamets holds the golden oyster mushroom *(Pleurotus citrinopileatus)* fruiting from pasteurized straw.

FIGURE 179

David Sumerlin examines oyster mushrooms *(Pleurotus ostreatus)* fruiting after immersion in a mycofiltration chamber. (See figure 72.)

FIGURE 180

The Brazilian blazei *(Agaricus brasiliensis* or *Agaricus blazei* ss. Heinemann) fruiting from leached cow manure indoors, using the methods described here.

FIGURE 181

The regal *Psilocybe cubensis* fruiting on leached cow manure outdoors. This mushroom is legal to cultivate in some countries but not in others.

FIGURE 182

Piles of mushroom compost at Fungi Perfecti made from spent sawdust fruitings. Once the mushrooms have fruited, the spent sawdust substrates (we call them "blocks") are thrown into a pile and turned every other month. The speed of this conversion of sawdust to dirt is remarkable—taking only 4 to 6 months—and illustrates the valuable role mycelium plays in building soil.

BY-PRODUCTS OF STRAW SUBSTRATE DUE TO CONVERSION BY *PLEUROTUS OSTREATUS*

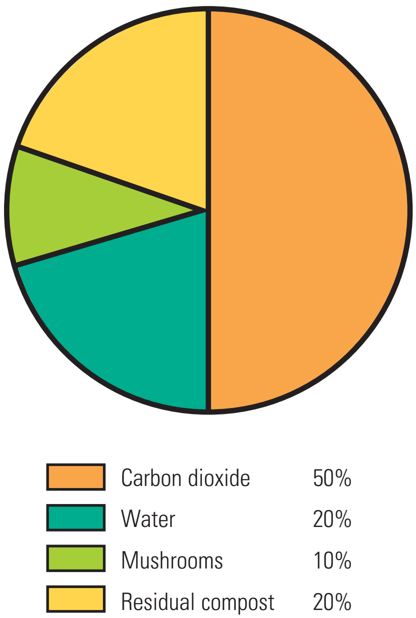


FIGURE 183

Pie chart showing proportion of carbon released relative to total mass. Carbon is either released as carbon dioxide, incorporated into mushroom tissue, or retained in the "spent" substrate prior to digestion by other microbes.

FIGURE 184

Plug spawn for inoculating logs. Mycelium grows in the grooves of the spiral dowel, helping it recover from the shock of inoculation.

List of Suitable Tree Species for the Cultivation of Gourmet and Medicinal Mushrooms

Scientific Name	Common Name
Abies spp.	Fir
*Abies alba***	White fir
Abies amabilis	Pacific silver fir
Abies magnifica	California red fir
Abies procera	Noble fir
Acacia spp.	
Acacia mangium	Forest mangrove
Acer spp.	Maples
Acer macrophyllum	Bigleaf maple
Acer negundo	Box elder
Acer rubrum	Red maple
Acer saccharum	Sugar maple
Ailanthus altissima	
Alniphyllum fortunei	Alders
Alnus spp.	White alder
Alnus alba	European alder
Alnus glutinosa	Gray alder
Alnus incana	Japanese alder
Alnus japonica	Red alder
Alnus rubra	Hazel alder
Alnus serrulata	
Alnus tinctoria	Tree of heaven
Altingia chinensis	
Arbutus spp.	Madrones
Arbutus menziesii	Pacific madrone
Betula spp.	Birches
Betula alleghaniensis	Yellow birch
Betula dahurica	
Betula lenta	Sweet birch
Betula nigra	River birch
Betula papyrifera	Paper birch
Betula pendula	European birch
Betula pubescens	Hairy birch
Carpinus spp.	Hornbeams
Carpinus betulius	European hornbeam
Carpinus caroliniana	American hornbeam
Carpinus fargesii	Asian hornbeam
Carpinus japonica	Japanese hornbeam
Carpinus laxiflora	Loose flower hornbeam
Carpinus orientalis	Oriental hornbeam
Carpinus tschonoskii	Korean hornbeam
Carpinus turczaninowii	
Carya spp.	Hickories
Carya aquatica	Water hickory
Carya cordiformis	Bitternut hickory
Carya glabra	Pignut hickory
Carya illinoensis	Pecan
Carya laciniosa	Shellbark hickory
Carya ovata	Shagbark hickory
Carya texana	Black hickory
Carya tomentosa	Mockernut hickory
Castanea spp.	Chestnuts
Castanea crenata	Japanese chestnut
Castanea henryi	Chinese chestnut
Castanea mollissima	Blume Chinese chestnut
Castanea sativa	Spanish chestnut
Castanea sequinii	
Castanopsis spp.	Chinquapins
Castanopsis accuminatissima	Berangan
Castanopsis argentea	Sarangan
Castanopsis caerlesii	
Castanopsis chinensis	Chinese chinquapin
Castanopsis chrysophylla	Golden chinquapin
Castanopsis cuspidata	Shii tree
Castanopsis fabri	White beam
Castanopsis fargesii	
Castanopsis fissa	Chestnut oak
Castanopsis fordii	
Castanopsis hickelii	
Castanopsis hystrix	Katus
Castanopsis indica	
Castanopsis lamontii	
Castanopsis sclerophylla	
Castanopsis tibetana	Tibetian chinquapin

Scientific Name	Common Name
Cinnamomum camphora	Camphor laurel
Cornus spp.	Dogwoods
Cornus capitata	Flowering dogwood
Cornus florida	Flowering dogwood
Cornus nuttallii	Pacific dogwood
Corylus spp.	Filberts
Corylus americana	American hazelnut
Corylus avellana	
Corylus heterophylla	Siberian hazelnut
Corylus maxima	
Distylium myricoides	
Distylium racemosum	Isu tree
Elaeocarpus chinensis	
Elaeocarpus japonicus	
Elaeocarpus lancaefolius	Bhadrase
Engelhardtia chrysolepis	
Eriobotrya deflexa	Bronze loquat
Eucalyptus spp.	Eucalyptus
Eucalyptus globulus	Tasmanian blue gum
Eucalyptus grandis	Grand eucalyptus
Eucalyptus saligna	Blue gum
Eucalyptus urophylla	
Eurya loquiana	
Fagus spp.	Beeches
Fagus crenata	Japanese beech
Fagus grandifolia	American beech
Fraxinus spp.	Ashes
Fraxinus americana	White ash
Fraxinus latifolia	Oregon ash
Fraxinus nigra	Black ash
Fraxinus pennsylvanica	Green ash
Fraxinus velutina	Velvet ash
Garcinia multiflora	Saptree
Hevea brasiliensis	Rubber tree
Juglans spp.	Walnut
Juglans nigra	Black walnut
Lagerstroemia subcostata	
Larix spp.	Larches
Larix laricina	Tamarack

Scientific Name	Common Name
Larix lyallii	Subalpine larch
Larix occidentalis	Western larch
Liquidambar spp.	Sweetgums
Liquidambar formosana	Formosa sweetgum
Liquidambar styraciflua	
Liriodendron tulipifera	Tulip poplar
Lithocarpus spp.	Tanoaks
Lithocarpus auriculatus	
Lithocarpus calophylla	
Lithocarpus densiflorus	Tanbark oak
Lithocarpus glaber	Japanese oak
Lithocarpus lanceafolia	
Lithocarpus lindleyanus	
Lithocarpus polystachyus	
Lithocarpus spicatus	
Mallotus lianus	
Malus spp.	Apples
Morus alba	White mulberry
Morus rubra	Red mulberry
Nyssa sylvatica	Tupelo
Ostyra spp.	Ironwood (hop hornbeam)
Ostyra carpinifolia	European hop hornbeam
Ostrya virginiana	American hop hornbeam
Pasania spp.	Shii tree
Peltophorum africanum	African wattle tree
Pinus contorta	Lodgepole pine
Pinus lambertiana	Sugar pine
Pinus ponderosa	Ponderosa pine
Platycarya strobilacea	Asian walnut
Populus spp.	Cottonwoods and poplars
Populus balsamifera	Balsam poplar
Populus deltoides	Eastern cottonwood
Populus fremontii	Fremont cottonwood
Populus grandidentata	Bigtooth aspen
Populus heterophylla	Swamp cottonwood
Populus nigra	Black poplar
Populus tremuloides	Quaking aspen
Populus trichocarpa	Black cottonwood
Prosopis spp.	Mesquite

List of Suitable Tree Species for the Cultivation of Gourmet and Medicinal Mushrooms, *continued*

Scientific Name	Common Name
Prosopis juliflora	Honey mesquite
Prosopis pubescens	Screw-pod mesquite
Prunus cerasifera	Cherry plum
Prunus domestica	European plum
Pseudotsuga menziesii	Douglas fir
Pyrus spp.	Pear
Quercus spp.	Oaks
Quercus acuta	Japanese evergreen oak
Quercus acutissima	Sawtooth oak
Quercus agrifolia	Californa live oak
Quercus alba	White oak
Quercus aliena	Oriental white oak
Quercus bella	
Quercus berberidifolia	Scrub oak
Quercus brandisiana	
Quercus chrysolepis	Canyon live oak
Quercus crispula	Japanese white oak
Quercus dentata	Emperor oak
Quercua dumosa	California scrub oak
Quercus emoryi	Emory oak
Quercus fabri	
Quercus falcata	Southern red oak
Quercus gambelii	Gambel oak
Quercus garryana	Oregon white oak
Quercus glauca	Japanese blue oak
Quercus grosseserrata	Mongolian oak
Quercus kelloggii	California black oak
Quercus kerii	
Quercus kingiana	
Quercus laurifolia	Laurel oak
Quercus lobata	California white oak
Quercus lyrata	Overcup oak
Quercus michauxii	Swamp chestnut oak
Quercus mongolica	
Quercus muehlenbergii	Chinquapin oak
Quercus myrsinae	
Quercus nigra	Water oak
Quercus nuttallii	

Scientific Name	Common Name
Quercus palustris	Pin oak
Quercus phellos	Willow oak
Quercus prinus	Swamp oak
Quercus rubra	Northern red oak
Quercus semiserrata	
Quercus serrata	Nara oak
Quercus spinosa	
Quercus variabilis	Gulcham namu
Quercus virginiana	Live oak
Rhus spp.	Sumac
Rhus glabra	Smooth sumac
Rhus succedanea	Arkol sumac
Robinia spp.	Locust
Robinia neomexicana	New Mexico black locust
Robinia pseudoacacia	Black locust
Salix spp.	Willows
Salix amygdaloides	Peachleaf willow
Salix exigua	Sandbar or coyote willow
Salix fragilis	Crack willow
Salix geyerana	Geyer willow
Salix lasiandra	Pacific willow
Salix lasiolepis	Arrow willow
Salix nigra	Black willow
Salix scouleriana	Scouler willow
Sapium discolor	
Sloanea sinensis	
Taxus spp.	Yews
Taxus brevifolia	Pacific yew
Tilia spp.	Lindens
Tsuga canadensis	Eastern hemlock
Tsuga heterophylla	Western hemlock
Ulmus spp.	Elms
Ulmus americana	American elm
Ulmus campestris	English elm
Ulmus glabra	Mountain elm
Ulmus laevis	Smooth elm
Ulmus parvifolia	Chinese elm

FIGURE 185

Logs are positioned on a table, and drills equipped with 5/16-inch drill bits are used to make holes. By making the holes 1½ times deeper than the plug is long, the grower forms a "cave" deep within the log, allowing the mycelium to fill the chamber.

FIGURE 186

Like some cultivators, Virginia Fraser likes to dip the ends of the logs to prevent invasion from competitor fungi. The holes are dabbed with molten cheese wax. A gourmet stainless steel baster is a good tool for efficiently placing a measured dose of wax in each hole.

FIGURE 187

Once inoculated, the logs are laid to rest on a pallet or stacked in shady areas. For drier locations, I recommend covering them with a shade cloth or tarp to buffer against wild fluctuations in humidity.

FIGURE 188

After 6 to 12 months, mycelium can be seen at the ends, showing discolorations, a sure sign that the logs are colonized end to end with mycelium. Note that the mycelia flow inward from the outer surface, where the spawn dowels were inserted.

FIGURE 189

Damien Pack coaxed a shiitake flush from this alder log by immersing it overnight in water 2 weeks before.

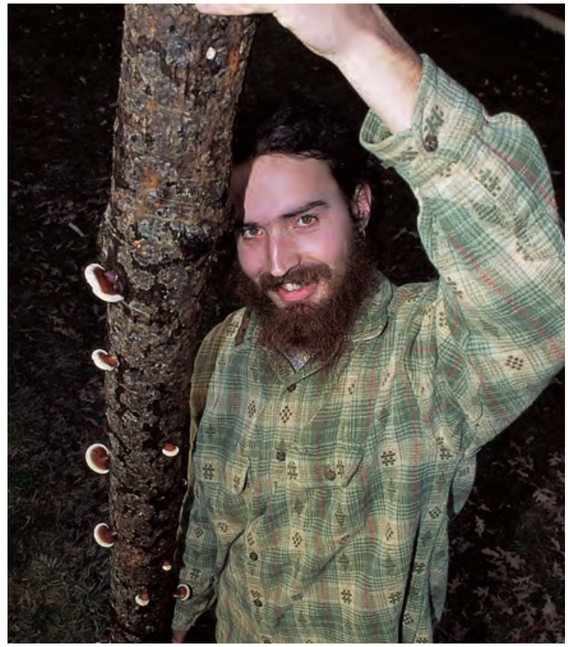


FIGURE 190

Steve Cividanes holds an alder log fruiting with reishi *(Ganoderma resinaceum).*

FIGURE 191

"Spaulded" (or "tiger") maple shaker box, made of wood from a log inoculated with reishi *(Ganoderma lucidum).* When using the beefsteak fungus *(Fistulina hepatica),* the wood is stained red, which increases the wood's value, especially oak, substantially. Many other species can be used for colorizing wood. The logs are usually milled 2 to 4 years after inoculation.

FIGURE 192

Once these pony logs are inoculated with plug spawn and the holes waxed over, Virginia Fraser places them into black plastic pots, which are then filled with sand. They can be conveniently stored underneath the benches of a standard greenhouse, benefiting from the added moisture and the stabilizing influence of contact with the ground.

FIGURE 193

About 6 months later, the mushrooms emerge, in this case reishi *(Ganoderma lucidum).*

FIGURE 194

David Brigham used a chain saw to scar these logs with wounds into which spawn will be placed.

FIGURE 195

Sawdust spawn of nameko *(Pholiota nameko)* covers the wounds and spans the gaps between the logs.

FIGURE 196

Fresh wood chips are placed atop the raft of spawned logs.

FIGURE 197

Once covered, the bed is left alone for a year. First fruitings can take up to 2 years, but this mycelial raft can produce mushrooms for a decade before exhausted. This method works well for species of *Hypholoma, Psilocybe, Stropharia, Agrocybe, Pleurotus* (oysters), *Ganoderma* (reishis), and others. I do not recommend this method for shiitake.

FIGURE 198

Inoculating stumps with plug spawn.

FIGURE 199

The best place to inoculate a stump is the inside of the peripheral edge, into the sapwood.

FIGURE 200

The clustered woodlover *(Hypholoma capnoides)* has fruited from this same stump for more than 10 years. Once a gourmet mushroom is established on a stump, you have years of delicious fungi to enjoy!

FIGURE 201

Oysters *(Pleurotus ostreatus)* and honey mushrooms *(Armillaria mellea* species) fruiting from the same stump. Such events suggest that oyster mushrooms, which are saprophytes, can be good competitors against honey mushrooms, which have a dual nature, first parasitic, killing trees, and then saprophytic, growing upon their dead tissue.

FIGURE 202

Oyster mushrooms *(Pleurotus ostreatus)* fruiting from coil of hemp rope. Rope spawn is an effective way to inoculate stumps.

FIGURE 203

Cauliflower mushrooms *(Sparassis crispa)* fruiting from hemp rope. This species, as well as woodlovers *(Hypholoma capnoides)*, an edible mushroom; *Hypholoma fasciculare*, a poisonous mushroom; and turkey tail *(Trametes versicolor)*, a medicinal mushroom, fight *Armillaria* root rot.

FIGURE 204

Two weeks after this log had been inoculated with sawdust spawn. Mealy bugs had already climbed up 2 feet to take up residence with the oyster mushroom mycelium, consuming it.

FIGURE 205

The author girdles a stump.

FIGURE 206

Rope spawn is tapped into the groove using a hammer.

FIGURE 207

Using 5/16-inch-diameter rope spawn, slightly swelled with water, makes insertion easy, since the chain saw cut is also 5/16-inch. If inoculating a live tree, two parallel girdles stuffed with rope spawn are recommended. (Note: Girdling a tree will kill it.)

Fruiting Seasons

Spring

Morel *(Morchella angusticeps* and *Morchella esculenta)*

Spring oysters *(Pleurotus ostreatus* and allies)

Summer

Reishis and allies *(Ganoderma species,* including *G. lucidum, G. curtisii, G. oregonense, G. resinaceum, G. tsugae,* and *G. applanatum)*

Garden giant *(Stropharia rugoso annulata)*

Elm oyster *(Hypsizygus ulmarius)*

Shiitake *(Lentinula edodes)*

Late Summer to Early Fall

Button and meadow *(Agaricus bitorquis, A. campestris, A. subrufescens,* and *A. brasiliensis)*

King oyster *(Pleurotus eryngii)*

Maitake *(Grifola frondosa)*

Parasol *(Macrolepiota procera* and *Chlorophyllum rachodes)*

Rocky mountain enoki *(Flammulina populicola)*

Cubies *(Psilocybe cubensis)*

Late Fall to Early Winter

Oyster *(Pleurotus ostreatus* and *Pleurotus pulmonarius)*

Shaggy mane *(Coprinus comatus)*

Sacred psilocybes *(Psilocybe azurescens, Psilocybe cyanescens,* and *Psilocybe cyanofibrillosa)*

Enokitake *(Flammulina velutipes)*

Blewitt *(Lepista nuda)*

FIGURE 208

Removing debris from future mushroom patch and laying down cardboard.

FIGURE 209

Distributing wood chips across the surface.

FIGURE 210

A layer of spawn is dispersed and 1 to 2 inches of more chips are added on top, sandwiching the underlying spawn.

FIGURE 211

Top-dressing with a shallow layer of fresh straw (1 to 2 inches).

FIGURE 212

A year later, David Sumerlin looks for mycelial growth and finds some surfacing. Note that the straw has mostly decomposed.

FIGURE 213

David scoops up an island colony of mycelium, a mycelial lens that can be transported and expanded by a factor of 10 in a single year. This mycelium—originally from pure culture sawdust spawn—is now naturalized, competing well with outdoor microbes, and running fast.

FIGURE 214

Baby garden giants *(Stropharia rugoso annulata)* huddled next to rapidly growing corn.

FIGURE 215

Christiane Pischl plants starts of several vegetable species in undernourished soil.

FIGURE 216

Adding pure sawdust spawn.

FIGURE 217

Laying down a layer of sawdust over the test beds.

FIGURE 218

Top-dressing with loose straw.

FIGURE 219

Once the beds are covered, straw is cleared from the plant stems to help trap water and aerate.

FIGURE 220

Three weeks later, the elm oyster *(Hypsizygus ulmarius)* fruits adjacent to the emerging plants, which appear healthy from this fungal pairing.

FIGURE 221

About a pound of fresh elm oyster mushrooms *(Hypsizygus ulmarius)* were picked from this bed a month after the bed was created.

FIGURE 222

Christiane Pischl hard at work maintaining the companion mushroom garden experiment at Fungi Perfecti, Kamilche Point, Washington.

FIGURE 223

With Brussels sprouts and other plants, we noticed significant increases in output, root wad development, and stem length when grown with mycelium.

FIGURE 224

The plants having contact with mycelium of the elm oyster *(Hypsizgus ulmarius)* produced much better than the controls.

Companion Planting Yield Results

Total yields comparing production from unmulched, mulched, mulched with mycelium of the elm oyster mushroom *(Hypsizygus ulmarius),* and mulched with mycelium of oyster mushrooms *(Pleurotus ostreatus).* d.w. = dry weight.

Bed Treatment	Yield Plants (d.w.)	Yield Mushrooms (d.w.)	Total (d.w.)	Total Fresh (g)
Control unmulched	100.5	0	100.5	904.5
Control mulched	73.7	0	73.7	663.3
Pleurotus ostreatus	42.6	114.5	157.1	1,413.9
Hypsizygus ulmarius	248.6	170.1	418.7	3,768.3

The garden giant *(Stropharia rugoso annulata)* also enhanced crop production within 25 percent of the elm oyster *(Hypsizygus ulmarius)* but did not fruit the first year.

FIGURE 225

Seeds of 8 garden vegetable species germinate 5 to 6 days after being soaked in water and are embedded within a common mycelial network that nurtures their growth.

FIGURE 226

Comparison of California poppies with and without mycorrhizal spores.

FIGURE 227

Comparison of potatoes with and without mycorrhizal spores.

FIGURE 228

Arugula roots encased with saprophytic mushroom mycelium, which helped this plant absorb nutrients.

The Nutritional Properties of Mushrooms

	Calories	Protein, g/100g	Fat, g/100g	Polyunsaturated Fat, g/100g	Total Unsaturated Fat, g/100g	Saturated Fat, g/100g	Carbohydrates, g/100g	Complex Carbohydrates, g/100g	Sugars, g/100g	Dietary Fiber, g/100g	Cholesterol, mg/100g	Vitamin A, IU/100g	Thiamine (B_1), mg/100g	Riboflavin (B_2), mg/100g	Niacin (B_3), mg/100g	Pantothenic Acid (B_5), mg/100g	Vitamin C, mg/100g	Vitamin D, IU/100g	Calcium, mg/100g	Copper, mg/100g	Iron, mg/100g	Potassium, mg/100g	Selenium, mg/100g	Sodium, mg/100g
Agaricus bisporus Button mushroom	340	33.48	2.39	0.41	0.44	0.26	46.17	24.27	21.90	19.10	0	0	0.23	3.49	38.50	21.70	0	26	9	20.80	4.8	4800	0.066	3
Agaricus bisporus Portobello	355	34.44	3.10	1.43	1.46	0.30	47.38	24.68	22.70	20.90	0	0	0.27	4.13	69.20	12.70	0	235	23	4.33	2.1	4500	0.415	52
Agaricus brasiliensis Brazilian Blazei	362	35.19	3.39	1.51	1.72	0.37	47.70	26.50	21.20	21.00	0	0	0.26	2.40	58.50	14.20	0	737	36	4.28	1.9	5200	0.35	43
Flammulina populicola Enokitake	346	26.59	3.06	1.08	1.22	0.23	52.95	30.55	22.40	25.80	0	0	0.35	1.69	60.60	10.90	0	113	14	0.61	8.3	3100	0.054	19
Ganoderma lucidum Reishi	376	15.05	3.48	0.50	1.20	0.27	71.00	69.30	1.70	66.80	0	0	0.06	1.59	12.40	2.70	0	66	37	1.30	13.0	760	0.014	6
Ganoderma oregonense Oregon polypore	367	13.27	2.52	0.21	0.48	0.01	72.79	72.09	0.70	72.00	0	0	0.20	1.49	20.90	2.10	0	32	18	1.10	4.3	850	0.039	2
Grifola frondosa Maitake	377	25.51	3.83	1.12	2.08	0.34	60.17	41.37	18.80	28.50	0	0	0.25	2.61	64.80	4.40	0	460	31	1.88	7.6	2300	0.056	14
Hericium erinaceus Lion's mane	375	20.46	5.06	0.83	1.85	0.76	61.80	40.90	20.90	39.20	0	0	0.16	2.26	11.80	7.40	0	57	8	1.66	6.0	2700	0.091	4
Lentinula edodes Shiitake	356	32.93	3.73	1.30	1.36	0.22	47.60	31.80	15.80	28.90	0	0	0.25	2.30	20.40	11.60	0	110	23	1.23	5.5	2700	0.076	18
Pholiota nameko Nameko	364	33.65	3.91	1.01	1.29	0.17	48.36	29.26	19.10	28.10	0	0	0.28	3.06	106.00	17.50	0	38	18	1.60	16.0	2500	0.103	4
Pleurotus djamor Pink oyster	356	30.20	2.86	0.91	0.97	0.16	52.76	29.66	23.10	43.80	0	0	0.26	2.45	65.80	33.20	0	136	5	1.61	11.0	4600	0.175	13
Pleurotus ostreatus Pearl oyster	360	27.25	2.75	1.16	1.32	0.20	56.53	38.43	18.10	33.40	0	0	0.16	2.04	54.30	12.30	0	116	20	1.69	9.1	2700	0.035	48
Pleurotus ostreatus var. columbinus Blue oyster	355	24.64	2.89	1.05	1.18	0.16	57.61	35.31	22.30	34.10	0	0	0.16	2.14	48.30	13.70	0	214	3	1.19	5.2	4400	0.083	31
Pleurotus pulmonarius Phoenix oyster	355	19.23	2.70	0.53	0.62	0.11	63.40	51.60	11.80	48.60	0	0	0.10	1.68	23.80	8.80	0	178	9	1.03	6.5	2600	0.09	16
Pleurotus tuber-regium King tuber	329	14.97	0.31	0.04	0.05	0.02	66.68	66.68	0.00	65.50	0	0	0.07	0.65	7.30	3.20	0	65	12	0.13	3.5	500	0.092	2
Trametes versicolor Turkey tail	369	10.97	1.51	0.27	0.32	0.06	77.96	76.06	1.90	71.30	0	0	0.07	1.06	9.30	1.70	0	62	34	0.65	8.7	570	0.007	6

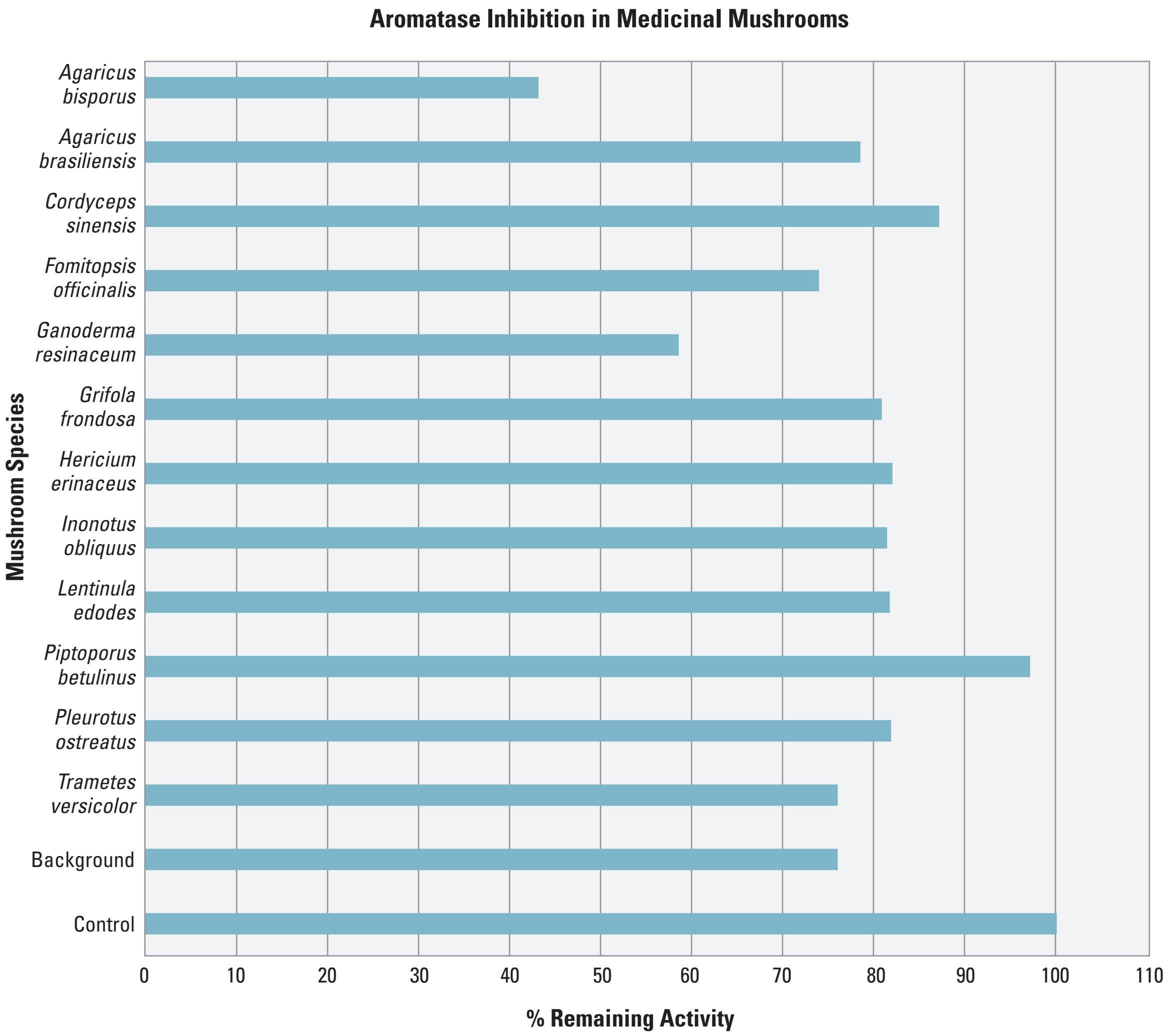


FIGURE 229

Aromatase inhibition by mushroom species. The lesser the value, the greater the inhibition of aromatase, significant for limiting the growth of breast cancer.

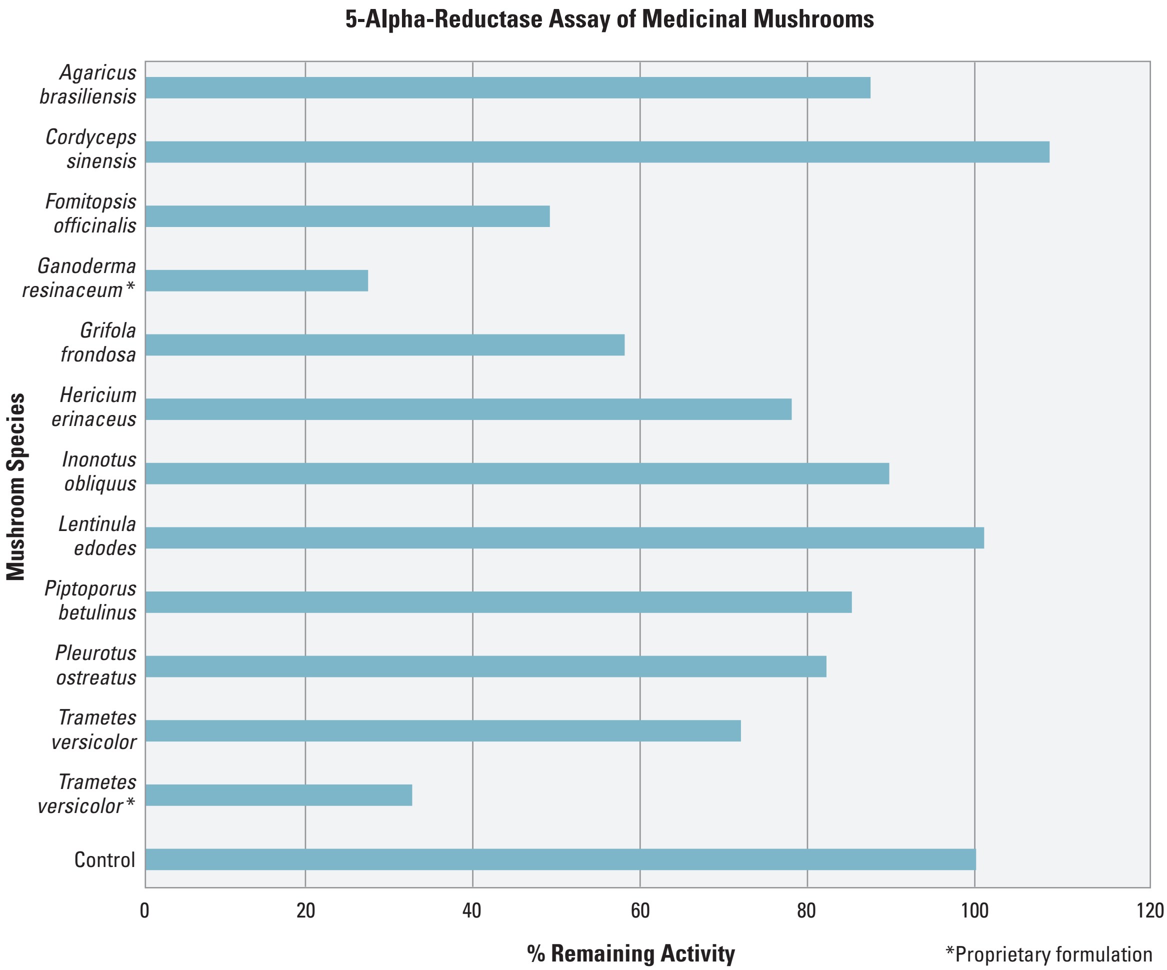


FIGURE 230

5-alpha-reductase inhibition by mushroom species. Mushrooms having lower values show greater inhibition of 5-alpha-reductase, significant for limiting the growth of prostate cancer.

Influence of Sunlight on Vitamin D Content in Mushrooms

Species	Form	Substrate	Growth and Drying Conditions	Vitamin D Content (IU/100g)
Shiitake *(Lentinula edodes)*	Fruitbodies	Sawdust	Grown in dark, dried in dryer	134
Shiitake *(Lentinula edodes)*	Fruitbodies	Supplemented sawdust	Grown in dark, dried in dryer	15
Shiitake *(Lentinula edodes)*	Fruitbodies	Supplemented sawdust	Normal growth conditions, filtered light, dried in dryer	110
Shiitake *(Lentinula edodes)*	Fruitbodies	Supplemented sawdust	Normal growth conditions, filtered light, sun-dried	21,400
Shiitake *(Lentinula edodes)*	Fruitbodies	Supplemented sawdust	Sun grown (fruiting from composted kit), dried inside	1,620
Shiitake *(Lentinula edodes)*	Fruitbodies	Supplemented sawdust	Normal growth conditions, filtered light, sun-dried, gills down	10,900
Shiitake *(Lentinula edodes)*	Fruitbodies	Supplemented sawdust	Normal growth conditions, filtered light, sun-dried, gills up	46,000
Shiitake *(Lentinula edodes)*	Stem butts	Supplemented sawdust	Normal growth conditions, filtered light, dried in dryer, ground into powder, no sun exposure	137
Shiitake *(Lentinula edodes)*	Stem butts	Supplemented sawdust	Normal growth conditions, filtered light, dried in dryer, ground into powder, 6–8 hours sun exposure	939
Shiitake *(Lentinula edodes)*	Mycelium	Rice	Grown inside, freeze-dried, no sun exposure	<20
Shiitake *(Lentinula edodes)*	Mycelium	Rice	Grown inside, freeze-dried, 6–8 hours sun exposure	<20
Reishi *(Ganoderma lucidum)*	Fruitbodies	Supplemented sawdust	Normal growth conditions, filtered light, dried in dryer, no sun exposure	66
Reishi *(Ganoderma lucidum)*	Fruitbodies	Supplemented sawdust	Normal growth conditions, filtered light, dried in dryer, 6–8 hours sun exposure	2760
Maitake *(Grifola frondosa)*	Fruitbodies	Supplemented sawdust	Normal growth conditions, filtered light, dried in dryer, no sun exposure	460
Maitake *(Grifola frondosa)*	Fruitbodies	Supplemented sawdust	Normal growth conditions, filtered light, dried in dryer, 6–8 hours sun exposure	31,900

FIGURE 231

Formerly called *A. blazei* by many, the regal *A. brasiliensis* is a popular medicinal mushroom with a strong almond flavor.

FIGURE 232

A. brasiliensis fruits from a tray filled with pasteurized leached cow manure. This majestic species produces mushrooms on a wide array of substrates—from supplemented sawdust to a variety of composts.

FIGURE 233

A. brasiliensis emerges from a cluster of rhizomorphic mycelium.

FIGURE 234

David Sumerlin prepares to dry freshly picked *A. brasiliensis*.

FIGURE 235

A star cluster of *A. aegerita* primordia.

FIGURE 236

A. aegerita fruits from a mushroom kit, also known as a sawdust production block.

FIGURE 237

Buried logs, arranged as a "log raft," fruiting with *A. aegerita*. The sawdust spawn—from an expired mushroom kit—was introduced the year before by placing it between the logs and against wounds created by a chain saw. The logs produced to 3 fruitings per year for more than 5 years. I suspect many *Agrocybe* species can be grown this way.

FIGURE 238

C. rachodes, also known as *Lepiota rachodes,* is great for decomposing grass clippings and fir needles.

FIGURE 239

After mowing our yard, La Dena Stamets gets ready to dump the grass clippings.

FIGURE 240

Sawdust spawn of *C. rachodes* is broadcast over the surface of the moist, rank grass.

FIGURE 241

La Dena places grass clippings on top of the spawn, creating a "mycelial sandwich." This patch is located in the shade beneath a fir tree along the edge of our yard.

FIGURE 242

Half a year later, a delighted La Dena Stamets rejoices as the first *C. rachodes* mushrooms appear. "I did it Dad!" she exclaims. The mushrooms have continued to fruit, without additional spawning, for more than 4 years at this same location. Feeding the mushroom patch regular lunches of cut grass is essential for keeping it alive.

FIGURE 243

C. comatus are stately mushrooms; they're easy to identify and are prime edibles.

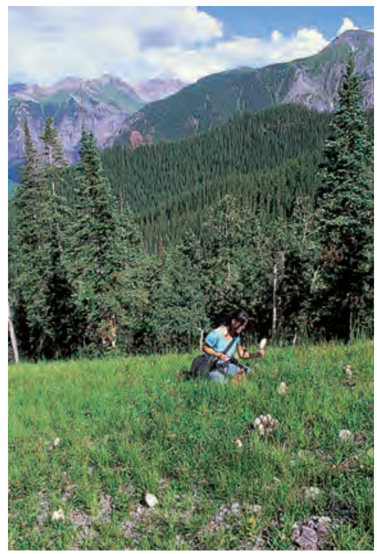


FIGURE 244

Dusty Yao picks *C. comatus* on the ski slopes above Telluride, Colorado.

FIGURE 245

C. comatus, a delicious choice edible mushroom and an indicator of habitats in transition. Here, Scott Oliver picks one of hundreds that came up in his lawn for many years. When he stopped fertilizing, the mushrooms did not reoccur. Some strains of *C. comatus* commonly form in yards in response to nitrogen-rich fertilizers.

FIGURE 246

Never underestimate the power of mushrooms! *C. comatus* busts through asphalt. They are well-known as road wreckers. Such Herculean events occur because mushrooms exert enormous upward forces when they fruit. Mycelium absorbs and pumps water into cells which are composed of a helical polysaccharide matrix, thus causing the mushrooms to push upward with pressures great enough to break asphalt, sometimes cement.

FIGURE 247

Wild *F. velutipes* bears little resemblance to its cultivated forms (see figures 249 and 250).

FIGURE 248

I cloned this strain from a mushroom picked from a log just below tree line above Telluride, Colorado. Identified as *F. populicola,* a sister species to *F. velutipes,* this strain produces more than 2,000 mushrooms from a 5-pound mushroom kit made mostly of sawdust!

FIGURE 249

Indoor-cultivated *F. velutipes* has become a large business. The uniformity of mushrooms grown in this fashion is remarkable.

FIGURE 250

Bottle culture of *F. velutipes* using heat-treated sawdust is the preferred commercial method primarily because of ease of harvesting and long shelf life. Enoki mushrooms change in form in response to environmental conditions to optimize spore release. The stems elongate as carbon dioxide outgasses from the mycelium's decomposition of the sawdust; the caps are small as a result of low light conditions.

FIGURE 251

Dusty Yao holds a tray of harvested *F. populicola*. Since these mushrooms were in a lighted greenhouse, their caps enlarged. With enokitake and many other mushrooms, light controls the diameter of the cap; carbon dioxide controls the length of the stem.

FIGURE 252

F. fomentarius is a perennial polypore. This conk formed several months after we inoculated sterilized birch, and in a year's time, we observed no fewer than 6 growth rings when slicing the mushroom in half. Conventional wisdom is that only 1 growth ring forms per year, reflective of the seasons, similar to tree rings. We find that if temperatures are conducive, spore layers form every couple of months.

FIGURE 253

F. fomentarius fruiting on downed birch near Burlington, Vermont.

FIGURE 254

Otzi's fire kit included this highly flammable mycelial wool made from boiling and separating the fibers within *F. fomentarius* conk. Also called the fire-starter mushroom, our ancestors' survival partially depended upon this species. This material was also useful as punk for black powder pistols and rifles, helping revolutionize warfare.

FIGURE 255

Bacterial colonies of *Escherichia coli* and mycelium of *F. fomentarius* grow toward each other on sterilized agar media.

FIGURE 256

Highly magnified octahedral "messenger crystals" secreted by *F. fomentarius* mycelium, advancing ahead of its leading edge prior to contact with coliform bacteria. I hypothesize that these crystalline entities disintegrate upon contact with microbial adversaries and leave a chemical scent trail that alerts the mother mycelium to the enemy in its path.

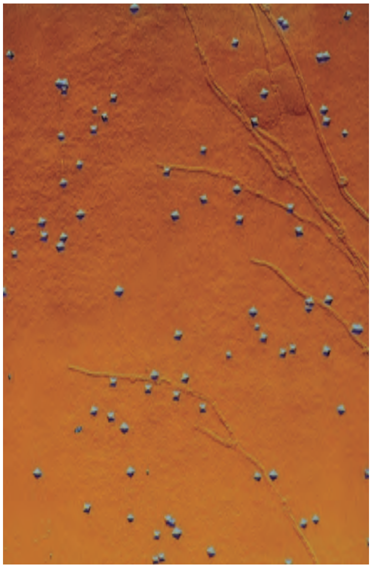


FIGURE 257

F. fomentarius generates secondary, larger crystals subsequent to its mycelium encountering the chemical scent trails from the disintegration of the primary crystals featured in figure 256. *Escherichia coli,* a dreaded coliform bacterium (rodlike cells in photo) pathogenic to both mushrooms and humans, is attracted to these secondary crystals, stunned, and then consumed as food by the encroaching mycelium. I was a member of the Battelle mycofiltration and mycoremediation team that first made this discovery using my proprietary strain of *F. fomentarius*. A predator-prey relationship also exists between the garden giant *(Stropharia rugoso annulata)* and this bacterium. These mushroom species can help in the mycofiltration of coliform bacteria in the runoff from pollution sources. The birch polypore *(Piptoporus betulinus)* secretes similarly shaped crystals, but I don't know if they also stun *E. coli.*

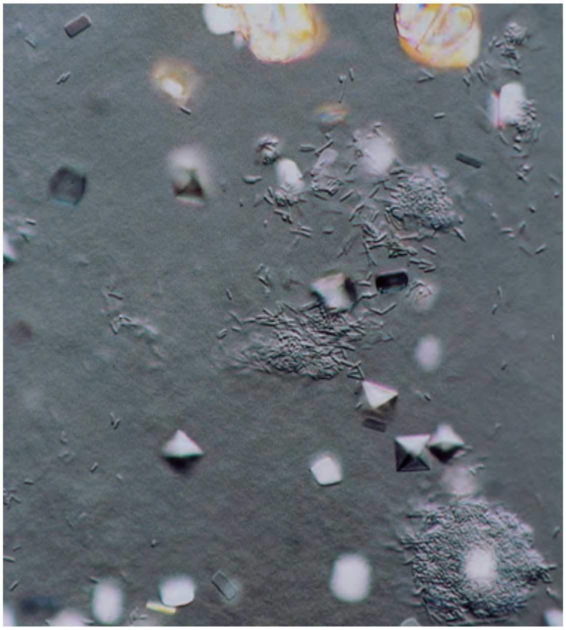


FIGURE 258

The outer conks are wild *F. fomentarius;* the inner one is cultivated. The hat is made by boiling these mushrooms, pounding them, and pulling apart their internal fabric—in essence separating the hyphae and then relayering to form a mycelial felt. Originating in Romania and Transylvania, this method of making hats from wood conks has been passed down through the centuries. *F. fomentarius* can be cultivated to produce felt just as silk factories use silkworms. I envision the rebirth of this age-old industry.

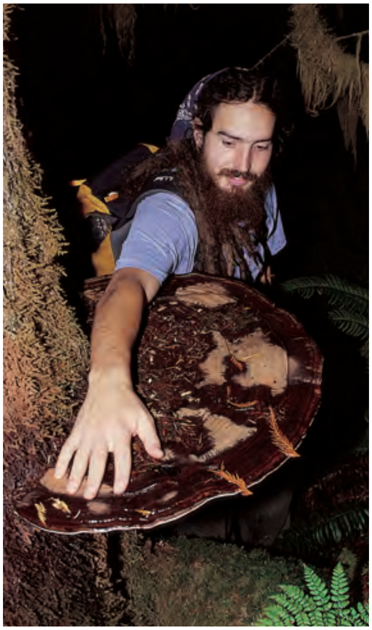


FIGURE 259

Steve Cividanes visits a massive artist conk deep in the old-growth forest on the Olympic Peninsula. This mushroom may produce enough spores to encircle the Earth. A small fragment of this conk was cut from the leading edge and brought to my laboratory, where I cloned it and created a culture.

FIGURE 260

This statuesque snag hosts *G. applanatum.* Three years later, the fungus had disintegrated this snag, leaving a feathery white pulp in its wake. The mycelium of this mushroom attracts many forestland insect species and is crucial in the recycling of nutrients in forestlands.

FIGURE 261

G. applanatum grows annual concentric rings that harden and become part of its internal structure; the leading edge builds new cells as it grows outward. Note the brown spores collecting on the upper surfaces.

FIGURE 262

G. applanatum makes a magnificent canvas for artists to etch upon.

FIGURE 263

Regal mushrooms, *G. lucidum* and allies are annual polypores. The white leading edge of the cap margin grows rapidly in warm temperatures.

FIGURE 264

Ancient portrait from China by Chen Hungsho (1599–1652), of Hou Chang holding *G. lucidum.*

FIGURE 265

When moist, the surface of reishi has a lacquered appearance. Whenever I see this mushroom, I am in awe of its beauty.

FIGURE 266

This short log inserted into a sand-filled nursery pot produces reishi mushrooms about 6 months after inoculation with plug spawn.

FIGURE 268

A *G. lucidum* laying yard. The advantages of ground contact are moisture and constant temperatures; the disadvantage is direct contact with biological competitors.

FIGURE 267

Reishi fruiting from an alder log 1 year after inoculation with plug spawn.

FIGURE 269

G. lucidum fruiting from a bundle of inoculated sticks in China.

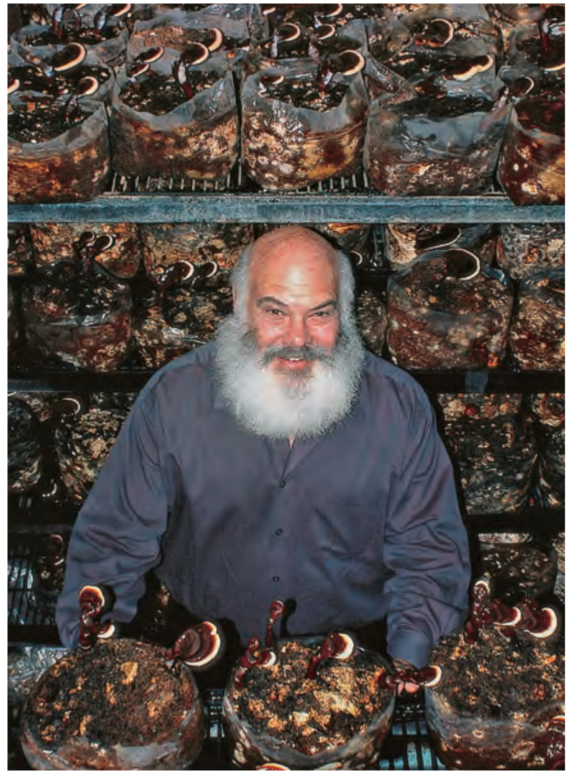


FIGURE 270

Dr. Andrew Weil, a longtime proponent of medicinal mushrooms, stands amongst *G. lucidum* fruiting in one of my growing rooms. All the mushrooms came from one culture, and if they touch, they will fuse together and continue to grow.

FIGURE 271

Co du Trong grew these *G. lucidum,* fruiting from sterilized sawdust, near Ho Chi Min City, Vietnam. After mixing rubber tree sawdust with bran and other materials, the substrate was brought to 212°F for 5 hours and, when cooled, inoculated with pure culture spawn.

FIGURE 272

Reishi drying in the sun. Exposing mushrooms to sunlight stimulates the conversion of ergocalciferols into vitamin D_2.

FIGURE 273

Ebikare Isikhuemhen happily holds a "hen" *(G. frondosa).*

FIGURE 274

A beautiful “hen,” ready for plucking, grows at the base of an oak tree.

FIGURE 275

Dusty Yao finds *G. frondosa* fruiting from the root remnants of a tree near Mercersburg, Pennsylvania, in October. We found several beautiful hens in the area that day. Bicycles are a rapid and effective vehicle for hunting for *G. frondosa* in suburbia.

FIGURE 276

Outdoor fruitings of *G. frondosa* arising from blocks buried into rocky soil.

FIGURE 277

Dusty Yao collects *H. abietis* in an old-growth forest near the slopes of Mount Rainier. This specimen was collected, cloned, and then consumed for a delicious dinner.

FIGURE 278

The clone from the mushroom featured in the previous image grows under sterile culture in a nutrient-filled petri dish. Note the small clusters of baby mushrooms forming.

FIGURE 279

H abietis fruits from Douglas fir wood chips and is genetically identical to the mushroom featured in figure 277. The time from collecting to cloning to fruiting was 4 to 5 months. Such cloning practices help preserve biodiversity by building a library of strains.

FIGURE 280

Dusty Yao holds photographs from one of her fall mushroom hunts with her sister Liz, who holds *H. erinaceus*. We cloned this mushroom and then grew it, as featured here, in only 3 months from the day of collecting.

FIGURE 281

Phan Ngoc Chi Lan stands between two rows of *H. erinaceus* in Vietnam.

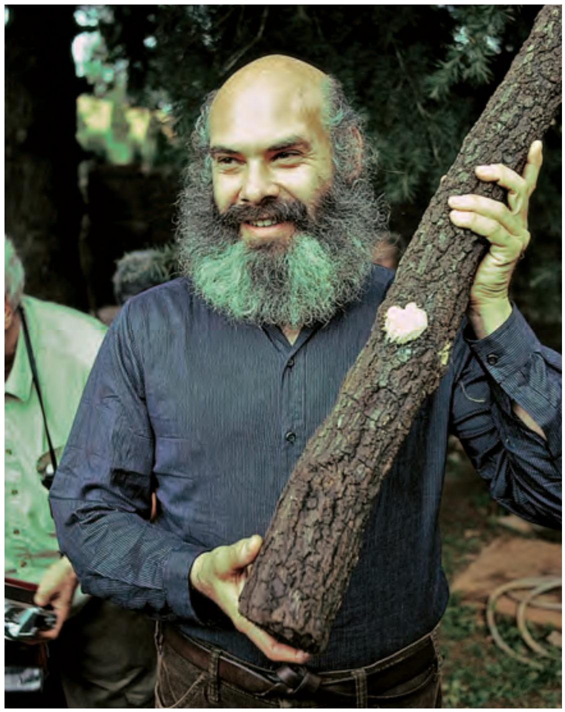


FIGURE 282

Dr. Andrew Weil holds a hardwood (oak) log hosting emerging *H. erinaceus* while traveling in China in 1984.

FIGURE 283

A young, emerging fruiting of *H. capnoides.* Note mature specimens off to the side.

FIGURE 284

H. capnoides grows on dead wood, primarily conifers, and is an aggressive saprophyte competing well against several parasitic fungi. I have observed that stumps and logs having this mushroom do not readily host *Armillaria* species, which are devastating root-rot parasites. Some conifer stumps can support species fruitings of hundreds of mushrooms each season over a decade.

FIGURE 285

H. capnoides has smoky gills when mature.

FIGURE 286

Here, *H. fasciculare,* a gastrointestinally poisonous mushroom with olive-greenish gills when mature lies beside *H. capnoides,* and edible mushroom, which has smoky brown gills when mature.

FIGURE 287

Galerina autumnalis, a deadly poisonous mushroom, is easily distinguished from *Hypholoma* mushrooms by spore color: *Galerina* mushrooms produce rusty brown spores, whereas *Hypholoma* species produce purplish brown to black spores. A mistake in identification, easily avoided by noting spore color, can be fatal. *Be careful.*

FIGURE 288

Mycelium of *H. capnoides,* a forest-friendly saprophyte, over-running a culture of *Armillaria mellea,* a blight fungus that devastates thousands of acres of forests.

FIGURE 289

H. capnoides fruits on a dead snag in the old-growth rain forest of the Olympic Peninsula.

FIGURE 290

The beautiful *H. sublateritium* fruiting from a block of sterilized sawdust.

FIGURE 291

H. sublateritium fruiting from a log raft 6 months after inoculation with sawdust spawn, which was packed between scarified logs. These logs produced, without additional care, for 8 years.

FIGURE 292

H. sublateritium likes to fruit in dense families, often clustered, making it easy to pick.

FIGURE 293

A cluster of *H. sublateritium* emerging from a buried alder log inoculated with plug spawn.

FIGURE 294

H. sublateritium growing in the garden next to corn. Corralling a garden with logs inoculated with this mushroom is one of many ways to use this species.

FIGURE 295

H. ulmarius fruiting on a cottonwood in the Sol Duc River valley in the rain forest on the Olympic Peninsula.

FIGURE 296

H. ulmarius fruiting in an experimental garden bed.

FIGURE 297

Chaga, the sclerotium of *I. obliquus,* on a birch tree in Quebec, Canada.

FIGURE 298

Chaga can be ground into a powder and made into an immune-enhancing tea. Chaga tea has been made for centuries in eastern Europe and Eurasia.

FIGURE 299

A massive *I. dryophilus* fruits at the base of this otherwise healthy oak. Is it a saprophyte, a parasite, an endophyte, or all of the above? I think this mushroom might prove to be a good medicinal.

FIGURE 300

L. sulphureus fruiting on a beech stump in Kentucky.

FIGURE 301

L. sulphureus fruiting on a conifer.

FIGURE 302

L. edodes is the most popular wood-decomposing cultivated mushroom in the world.

FIGURE 303

L. edodes flushing from eucalyptus logs in Brazil.

FIGURE 304

L. edodes fruiting on oak logs in Washington State.

FIGURE 305

L. edodes fruiting from an alder log.

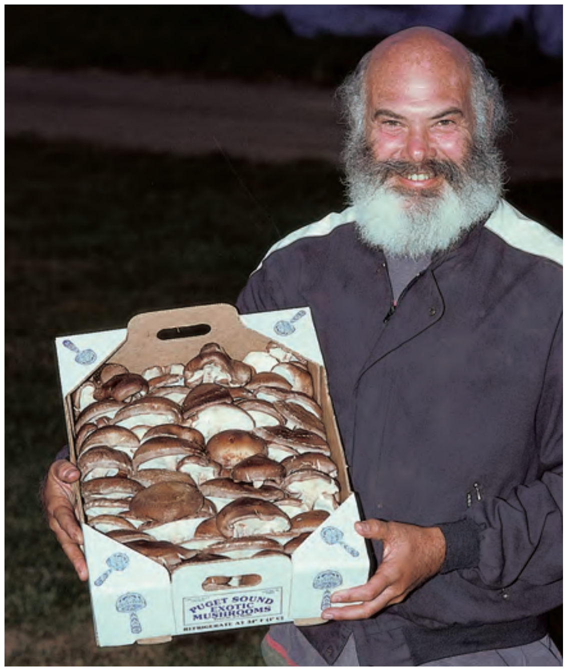


FIGURE 306

Dr. Andrew Weil holds a harvest of our organically grown shiitake.

FIGURE 307

L. edodes flourishes from one of our mushroom kits. Independent of the number of mushrooms that form, the yield remains about the same. The more mushrooms that are produced, the smaller they are; while conversely, the fewer mushrooms that form, the larger they are. A 5-pound sawdust kit produces about 1 pound of fresh mushrooms. The spent kit can be used as spawn for inoculating logs, or it can be repeatedly sterilized and reinoculated, giving rise to more fruitings, though shrinking each time until expiring.

FIGURE 308

The stately *M. procera* first fruited from a spawned patch and then spread, with satellite colonies erupting in multiple locations on our property. They grow very quickly. See the next photo for these same mushrooms just a day later.

FIGURE 309

One day later, the cap expands, the partial veil becomes a membranous ring on the stem, and the gills flare as white spores are released. A poisonous look-alike, *Chlorophyllum molybdites,* can be deadly but has greenish spores, not white, which makes it easy to distinguish from this mushroom.

FIGURE 310

Several dozen mushrooms sprouted in front of our laboratories, making for many *M. procera* feasts.

FIGURE 311

Parasol mushrooms often come up in groups, usually synchronized in their growth. Such flushes as seen here “captivate” and “bemushroom” all those who discover them.

FIGURE 312

M. procera sawdust-chip spawn is spread over a thatch ant mound. Expecting a ferocious reaction, I was surprised when the ants calmly went about distributing the mycelium, unperturbed by my invasive action. Curious.

FIGURE 313

Two days later, all the spawn has been incorporated into the nest as part of its architecture, leaving behind the large chips that were in the sawdust-chip spawn. We await the fruitings—how long? Nature knows.

FIGURE 314

The black morel, a complex containing *M. angusticeps* and *M. conica.*

FIGURE 315

Yellow morels, a complex encompassing *M. esculenta* and *M. deliciosa.* The specimens featured here came from an old apple orchard in Washington State.

FIGURE 316

This yellow morel *(M. esculenta)* emerged from this sclerotium-like tuber. This mushroom was growing under mature Douglas fir trees near Olympia, Washington. Morels grow from these types of subterranean masses, which can be variable in form.

FIGURES 317

Damein Pack, lead grower at Fungi Perfecti, inoculates a bonfire site with morel sawdust spawn.

FIGURE 318

When spawned in the summer to fall, black morels usually pop up the following spring.

FIGURE 319

This field of *M. esculenta* is a find of a lifetime and a dream come true!

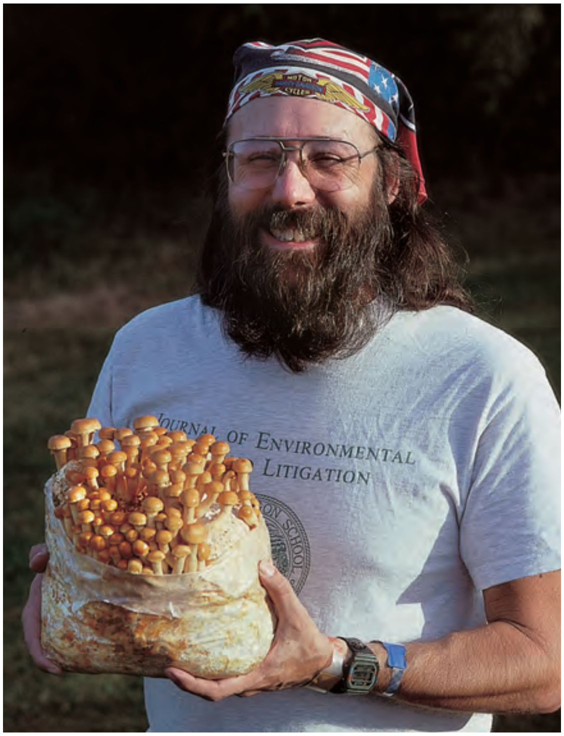


FIGURE 320

The estimable Albert Bates of Mushroompeople holds one of our *P. nameko* kits. Once harvested, the mycelium in the kit is still alive and will regrow if placed onto newly cut wood. Additionally, the stem butts of the mushrooms can be used for growing more mycelium.

FIGURE 321

Six months after inoculating, *P. nameko* fruits from partially buried alder logs spawned from a spent mushroom. Once established, fruitings of this mushroom recur for a long time.

FIGURE 322

P. betulinus fruiting on a paper birch *(Betula papyrifera).*

FIGURE 323

Dr. Christian Ratsch photographs *P. betulinus* in Germany.

FIGURE 324

A wild *P. eryngii* attached to the base of a carrot plant.

FIGURE 325

P. eryngii var. *nebrodensis,* a white variety of the king oyster, is increasing in popularity as a premier gourmet mushroom.

FIGURE 326

The classic oyster mushroom *(Pleurotus ostreatus)*, fruits from a cut face of a log.

FIGURE 327

Oyster mushrooms fruiting on a dead tree.

FIGURE 328

Grey and pink oyster mushrooms fruiting from a straw-stuffed chair.

FIGURE 329

Oyster mushrooms fruiting from inoculated logs placed over an irrigation slough. Here, wedges were cut out, the cavities were packed with sawdust spawn, and the wedges were reinserted.

FIGURE 330

Oyster mushrooms fruiting from rope. This rope spawn is ideal for inoculating notched stumps.

FIGURE 331

David Brigham inserts rope spawn of oyster mushrooms into a groove made by a chain saw.

FIGURE 332

Dusty Yao holding a bucket of oyster mushrooms fruiting from coffee grounds. Coffee grounds from espresso are essentially steam pasteurized, so are perfect for growing oyster mushrooms. The mushrooms break down the caffeine, an important effect that can help prevent caffeine toxicity from the runoff from coffee plantations.

FIGURE 333

A cluster of a sporeless strain of *P. ostreatus.* This unique strain has nude gills, free of any hymenium or basidia.

FIGURE 334

Wild *P. cubensis,* here growing in Palenque, Mexico, has a long history of use by indigenous peoples. A so-called "magic" mushroom, this mushroom is legal in some countries and illegal in others. Before cultivating, please check the legal status of this mushroom. Be careful.

FIGURE 335

P. cubensis is a stately mushroom, emanating an air of elegance and beauty, traits long admired by those who have grown and picked it.

FIGURE 336

During the 1970s and 1980s, it became popular for college students to grow *P. cubensis* in grain filled jars, often in closets converted into mini-growing rooms.

FIGURE 337

A hoop frame covered with black plastic loosely draped to just above the ground provides a humid and warm environment for outdoor cultivation during the summertime, as this garden demonstrates.

FIGURE 338

Untarped once or twice a day for misting, mushrooms erupt as a unified flush from pasteurized leached cow manure. Many mushrooms can be grown in this fashion outdoors. Tightly woven white "bug-out" cloth can also be used, provided high humidity and moisture can be maintained. These mushrooms orient toward light and incoming airflow.

FIGURE 339

These rapidly growing mushrooms can mature in a single day.

FIGURE 340

A primordial cluster of *P. cubensis* explodes from a mound of pasteurized leached cow manure. Here, asbestos-free vermiculite is placed upon the beds to retain moisture. Although vermiculite limits contaminants and helps mushrooms form, it is messy and requires extra effort to clean the vermiculite particles and dust from harvested mushrooms.

FIGURE 341

A multi-canopied overgrowth of trees provides shade and helps prevent evaporation, buffering microclimates, stimulating mushroom growth, and decreasing the need for watering.

FIGURE 342

The wood chip–loving *P. cyanescens* is characterized by wavy caps, silky stems, and bruising bluish.

FIGURE 343

A private *P. cyanescens* mushroom patch.

FIGURE 344

Mycelium on birch dowels—grown from stem butt spawn—grasps the wood with its lacy rhizomorphs. This spawn, when planted into more wood chips, grows mushrooms in 6 to 12 months, given conducive conditions. The following photograph depicts the mushrooms grown from this form of natural spawn.

FIGURE 345

Buddha overlooks a *Psilocybe* garden. This species, not yet named, heralds now from the San Francisco Bay Area and probably is new, or least a newly imported species.

FIGURE 346

If burlap bags stuffed with wood chips are inoculated with sawdust, dowel, or stem butt spawn, the mycelium fully colonizes in 4 to 6 months, typically over winter in the Pacific Northwest.

FIGURE 347

A species related to *P. cyanescens* is *P. azurescens*. Both enjoy wood chips actively being overgrown with grasses. The grasses collect dew, which streams down their stems to the ground, encouraging mushrooms to form.

FIGURE 348

Another close relative to *P. cyanescens* is *P. azurescens,* which also loves grasses growing through wood chips.

FIGURE 349

Cauliflower mushrooms like these *S. crispa* are superb edibles and, in my opinion, guard forest ecosystems from attack by quick-to-kill fungal blights, such as *Armillaria* root rot.

FIGURE 350

S. crispa fruiting from hemp rope. This rope can lasso notched stumps, inoculating them with mycelium of this *Armillaria*-fighting species. Once in place, the cauliflower mushroom can fruit for years.

FIGURE 351

S. rugoso annulata growing in a mixture of soil and wood chip hosting grasses. *Stropharia* and *Psilocybe* mycelium love root masses of grasses, especially when infused with wood chips.

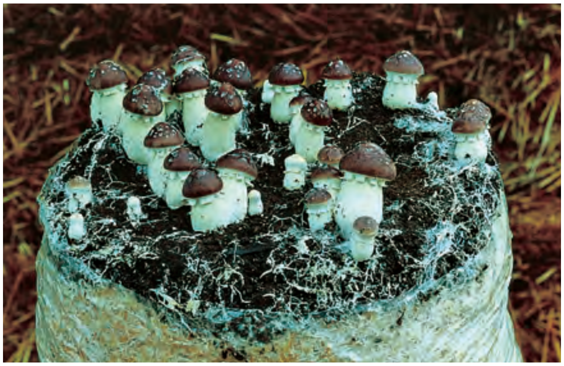


FIGURE 352

A flush of baby *S. rugoso annulata* fruits from cased, pasteurized wheat straw. Note the rhizomorphs channeling nutrients to primordia and adolescent mushrooms.

FIGURE 353

This wood chip garden of *S. rugoso annulata* produced hundreds of mushrooms over several years. The yearly influx of new chips kept the bed alive. Three years after the last influx of wood chips, the fruitings ceased and the colony moved on. Note the ganglion of rhizomorphs attached to stem bases.

FIGURE 354

Azureus Stamets holds a specimen of *S. rugoso annulata* estimated to weigh around 3 pounds. Car-stoppers, these mushrooms are best grown in the backyard, out of sight by drive-by mushroom hunters.

FIGURE 355

S. rugoso annulata fruiting in unison in a mulch bed in New Zealand. Note the regal crowns with toothlike decorations below the caps. These will soon fall into a membranous ring, also known as an *annulus*. See next photo.

FIGURE 356

The same garden giants as in the previous figure, 2 days later, in a majestic display of mycological beauty. Note how the membranous rings have now fallen from the caps and the characteristic purplish brown to black spores dust their upper sides.

FIGURE 357

T. versicolor comes in many colors and has beautiful zonations on the caps. This is one of the most common mushrooms in woodlands throughout the world, here fruiting on an aspen log.

FIGURE 358

An oak stump explodes with *T. versicolor* mushrooms. In essence, this stump is a powerfully medicinal platform, producing artful mushrooms with highly anticarcinogenic and mycorestorative properties.

FIGURE 359

T. versicolor fruits from a conifer log in the old-growth forest of the Olympic Peninsula.

FIGURE 360

This turkey tail strain is one I cloned from a broken branch from my apple tree. Actually, when my kids were toddlers, they jumped on Dr. Andrew Weil while he was laying in our hammock that was supported by two apple trees. One of the branches broke and Andy hit the ground with a thud and with gleeful kids on board. I threw the branch into the bushes. Turkey tail mushrooms fruited which I cloned, giving rise to the mushrooms seen here. This strain shows strong activity against prostate and other cancers. Such is the way science meanders forward.

The End . . .

of the beginning of the mycorestoration revolution . . .