mycotopia

an environment wherein
ecological equilibrium
is enhanced through the
judicious use of fungi

CHAPTER 7
ASHORE

Superfluous were the Sun
When Excellence be dead (999)

Until recently, when I visited the Star Trek commemorative exhibit at the Smithsonian Air and Space Museum in Washington, I had never seen a single *Star Trek* episode. For ten minutes, indolent curiosity, nostalgia for the 1970s, and the crowds at my back induced me to watch it: very United Statesian and very dated. I was struck by its silliness. The lack of plants, the machinate landscape, and in the starship, the absence of all nonhuman life-forms seemed bizarre. Humans, if someday they trek in giant spaceships to other planets, will not be alone. In space as on Earth, the elements of life, carbon, oxygen, hydrogen, nitrogen, sulfur, and phosphorus and a few others, must recycle. This recycling is no suburban luxury; it is a principle of life from which no technology can deliver us. Human voyages into deep space require ecosystems composed of many nonhuman organisms to recycle waste into food. Only very short stints in constant contact with mother Earth are possible in the absence of 'ecosystem services.'

An ecosystem is the smallest unit that recycles the biologically important elements. Carbon dioxide is 'fixed,' chemically converted to food and body (organic carbon). Organic carbon is respired, is reacted, is degraded or transformed to different kinds of organic matter. Eventually someone's enzyme or deep breathing reacts with that organic carbon to release from it CO_2. In this sense carbon is cycled. The same can be said of nitrogen as it goes from sluggish N_2 of the atmosphere, via 'nitrogen fixatives,' to the useful N of amino acids. When amino acids released from proteins are converted to nitrogen waste and after conversions become the N_2 of gas in the air it is said that the nitrogen cycle is complete. Elements cycle faster within ecosystems than between but no chemical is entirely isolated. I prefer the idea that Earth is a network of 'ecosystems' over any personification of Mother Gaia. My colleague Daniel Botkin would probably define any ecosystem as a set of communities of different species of organisms, living in the same place at the same time, enjoying an influx of external energy and matter. He'd claim, and I agree, that an ecosystem is a volume of Earth surface where organisms recycle energy and matter at a faster rate inside the system than between it and other systems. The material and energy needs of organisms in any ecosystem are met by recycling all of the many chemical compounds required for life maintenance. To 'green' Mars, to colonize other planets, or to live for extended periods in space will, of course, require far more than just human settlers and machines. It will require organized, efficient communities. Living together will be as crucial to the colonization of outer space as symbiosis and diversity were to the Paleozoic Era colonization of dry land. Life in space, if it is to occur, will require physical alliances, including new symbioses, among differing life-forms.

New symbioses, forging new patterns of interaction, have been crucial in the colonization of important parts of Earth. Land dwellers may owe their hold on dry ground to specific symbioses between plants and fungi.

Plant roots and fungi grow together into bumps on roots called mycorrhizae (Fig. 5). Together, fungal–plant complexes settled inhospitable dry regolith: sand, soil, and pebbles.

Life evolved in the sea, but the argument is strong that only interliving – symbiogenesis – made habitation of the hostile new dry land possible for life. Solar ultraviolet radiation, devastating desiccation, and nutrient scarcity were much more serious problems on land 500 million years ago than they are now.

Symbiogenesis developed the Earth's terra firma into occupiable real estate. The early landlocked symbioses were likely not bacterial. The oldest large land organisms that left a fossil record probably were plant–fungal complexes. The oldest plant fossils in the world come from chert, a kind of rock popularly called black flint. The best, most plant-fossiliferous chert comes from a quarry near Rhynie,

Scotland. Rhynie fossils are thought to have been preserved in such exquisite detail because of the flow of penetrating water from a nearby silica-rich hot spring. Among the Rhynie chert treasures are fossil chytrids, a kind of protoctist, inside fossilized algae. The algae themselves live inside the stems of 400-million-year-old plants! The quality of the snapshots the fossils give us of the earliest life on land is astounding. One insect preserved intact in Rhynie chert carried in its gut a fungal chlamydospore. (This fancy name refers to a structure resistant to cold and to drying out. Chlamydospores are propagules formed, without any sex, by the partitioning off of fungal threads.)

Canadian botanists K. A. Pirozynski and D. W. Malloch propose the idea of 'fungal fusion' to help explain the origin of plants 450 million years ago. They hypothesize coevolution of fungi and algae, the partners combined in symbiogenesis. Ultimately plants provided sap for internalized fungi whose mycelial threads developed tough branching and roots. Peter R. Astatt, of the University of California, Irvine, extends the Pirozynski–Malloch hypothesis, pointing out that plants break down cellulose walls of their cells by using the degradative and absorptive tricks of fungi. Both fungi and plants, for example, secrete chitinase enzymes into the soil. Astatt argues that during their long association with fungi, plants stole and retained fungal genes.

Today mycorrhizae are swollen symbiotic structures, distinct and recognizable. Often colorful, they form symbiogenetically by an interaction of fungi and the root tissue of plants. Mycorrhizae provide the plant partner with mineral nutrients, supplying it with soil phosphorus and nitrogen. The plant supplies the fungal partner with sap, photosynthate food. Mycorrhizal fungi today make chlamydospores strikingly similar to those found in the ancient fossils. Even 450-million-year-old plant remains in the Rhynie chert, including *Rhynia* itself, have swollen roots. Fungi and plants were already locked in productive symbioses at the very beginning of their tenure on dry land.

The move to land was synonymous with the evolution of plants from water-dwelling algae. Survival on land required fortitude: strength, desiccation resistance, and adequate nutrition. Astatt, who has not convinced his colleagues, states that these great discontinuities from the ancestral alga's habitat required symbioses between algae and fungi. Green algae, floating at the ocean's edge, did not just grow big and one day become a plant.

The desert valleys of Antarctica's Victoria Land are an icy hell. Gusts of wind periodically blow over rock and instantaneously freeze the melting ice of summer. Nonetheless, hidden two or three millimeters beneath the rock thrive communities of lichens, a symbiotic mix of fungi, algae, and bacteria that even inhabits porous sandstone. As long as this community can sun itself through the crystalline grains of quartz, it lives. An estimate of the global weight of such fungus–lichen rock dwellers is 13×10^{13} tons, a

biomass greater than all life in the ocean! Algae growing under protective cover of fungi cling to sheer rock, extend over its face, and ultimately break it down into soil that can be penetrated by roots of plants and fungal hyphal networks. The hard rock of this spinning planet has been crumbling for hundreds of millions of years into rich, nutritive soil as a result of the fungal–algal partnerships. Lichens, too, are major players in making land habitable for life in temperate climes.

Over billions of years, life, in what the McMenamins call 'Hypersea,'[1] extended its domain from its watery home onto dry land. With elegance, novelty, and shocking prodigiousness, life expanded into places it had never gone before. Today the number and diversity of species on land, and species interconnections, exceed those in the sea, which was life's original habitat. The biomass of life on land is hundreds if not thousands of times greater than the biomass of life in the seas. Much of this massive presence, an estimated 84 percent, is taken up by trees. The foresting of Earth, the dramatic expansion of life beyond its oceanic source, entailed a dramatic restructuring of the terrestrial environment. For photosynthesizers nutrients such as sulfate and phosphorus that floated freely through the water, the external circulatory system of the oceans, were in short supply on land. These nutrients had to be conducted by the hypersea network itself. The move to land entailed new architecture and infrastructure.

Where life dwelled, water flowed through it. Cytoplasm is more than 80 percent water. Mark McMenamin and his wife, the paleontologist Dianna McMenamin, call attention to the profound results of symbiogenetic interconnections with the catchy name 'hypersea.' What the McMenamins refer to as hypersea is largely the root system of plants that depend on mycorrhizae fungi. Over five thousand kinds of mycorrhizae symbionts, fungi tangled in plant root hairs, can be recognized by name. Vascular plants, of which *Rhynia* is an early example, include all plants except mosses, liverworts, and a few other damp ground covers. Vascular plants have circulatory systems. They are able to pump water from the ground toward their stems and leaves and distribute photosynthate (food) downward. Inconspicuous and underappreciated are their microscopic, mycorrhizal subterranean connections; the literal low profile of the partnerships explains the prodigious success of the plants we see.

Although globally important, mycorrhizal fungi rarely attract notice, except, for example, when they form truffles. These Italian and French delicacies are reproductive spore-forming parts of certain aromatic mycorrhizal fungi attractive to pigs and dogs, which sniff them out of the roots of hardwood trees. Plants with root mycorrhizae are naturally selected: in nutrient-deficient soils they produce heavier seedlings, with greater stores of nitrogen and phosphate, than their counterparts unlinked to fungi. Indeed, 90 percent of living plants have mycorrhizal symbionts. Over 80 percent of all plants perish if deprived of these fungal associates. Hypersea reigns.

The McMenamins' concept needs critical assessment and critical acclaim. Russian mineralogist Vladimir Vernadsky (1863–1945) recognized life as the great geological force. Anticipating Hypersea, he called living matter 'animated water.' Animated water is an excellent description of life.[2]

Plants made the move to land by re-creating their wet environment and sealing it within themselves. Trees are prolifically adept at sealing in water, moving it to land, and controlling its evapotranspiration. With their branching networks of tissue strengthened by cellulose and lignin, trees are, of course, vascular plants. Lignin is a complex combination of polyphenolic carbon chemicals that give wood its hardness. The appearance of trees, over 400 million years ago, spurred the entire biosphere upward and outward. The great expansion on land up and out of both sea and fresh water was grounded in the intimacy of plant with fungus, and it still is. Fungi are preeminent in the kingdom of land dwellers. Never photosynthetic, they obtain their food through absorption. They always lack undulipodia so their cells never swim. But wow, can they survive temporary desiccation! Fungi have patience that far exceeds that of any saint. They sit and wait, and when dampness reappears they take over. Most fungi form intricate mycelial networks, meshes of cytoplasm-filled feeding tubes. Alone, in concert with algae as lichen, or with plant roots as mycorrhizae, they conquered the land and multiplied.

Symbiogenesis was the moon that pulled the tide of life from its oceanic depths to dry land and up into the air. The network of water on land, the animated water of fungi in plants, is the McMenamins' Hypersea. If people ever journey for extended periods in outer space, the endeavor will never be as machinate and barren as *Star Trek*. The vision of sterile engineering emancipating us from our planetmates is not only tasteless and boring, it borders on the hideous. No matter how much our own species preoccupies us, life is a far wider system. Life is an incredibly complex interdependence of matter and energy among millions of species beyond (and within) our own skin. These Earth aliens are our relatives, our ancestors, and part of us. They cycle our matter and bring us water and food. Without 'the other' we do not survive. Our symbiotic, interactive, interdependent past is connected through animated waters.

CHAPTER 2

The Role of Mushrooms in Nature

Ecologically, mushrooms can be classified into three groups: the *saprophytes,* the *parasites* and the *mycorrhizae*. Although this book centers on the cultivation of gourmet and medicinal saprophytic species, other mushrooms are also discussed.

The Mycorrhizal Gourmet Mushrooms: Matsutake, Boletus, Chanterelles & Truffles

Mycorrhizal mushrooms form a mutually dependent, beneficial relationship with the roots of host plants, ranging from trees to grasses. "Myco" means mushrooms while "rhizal" means roots. The filaments of cells which grow into the mushroom body are called the *mycelium.* The mycelia of mycorrhizal mushrooms can form an exterior sheath covering the roots of plants and are called *ecto*mycorrhizal. Or they can invade the interior root cells of host plants and these are called *endo*mycorrhizal. In either case, both organisms benefit from this association. Plant growth is accelerated.

The resident mushroom mycelium increases the plant's absorption of nutrients, nitrogenous compounds, and essential elements (phosphorus, copper and zinc). By growing beyond the immediate root zone, the mycelium channels and concentrates nutrients from afar. Plants with mycorrhizal fungal partners can also resist diseases far better than those without.

Most ecologists now recognize that a forest's health is directly related to the presence, abundance and variety of mycorrhizal associations. The mycelial component of top soil within a typical Douglas fir forest in the Pacific Northwest approaches 10% of the total biomass. Even this estimate may be low, not taking into account the mass of the endomycorrhizae and the many yeast-like fungi that thrive in the topsoil.

The nuances of climate, soil chemistry and predominant microflora play determinate roles in the cultivation of mycorrhizal mushrooms in natural settings. I am much more inclined to spend time attempting the cultivation of native mycorrhizal species than to import exotic candidates from afar. Here is a relevant example.

Truffle orchards are well established in France, Spain and Italy, with the renowned Perigold black truffle, *Tuber melanosporum,* fetching up to $500 per lb. (See Figure 7). Only in the past 30 years has tissue culture of Truffle mycelium become widely practiced, allowing the development of planted Truffle orchards. Land owners seeking an economic return without resorting to cutting trees are naturally attracted to this prospective investment. The idea is enticing. Think of having an orchard of oaks or filberts, yielding pounds of Truffles per year for decades at several hundred dollars a pound! Several companies in this country have, in the past 12 years, marketed Truffle-inoculated trees for commercial use. Calcareous soils (i. e. high in calcium) in Texas, Washington and Oregon have been suggested as ideal sites. Tens of thousands of dollars have been exhausted in this endeavor. Ten years after planting, I know of only one, possibly two, successes with this method. This discouraging state of affairs should be fair warning to investors seeking profitable enterprises in the arena of Truffle cultivation. Suffice it to say that the only ones to have made money in the Truffle tree industry are those who have resold "inoculated" seedlings to other would-be trufflateurs.

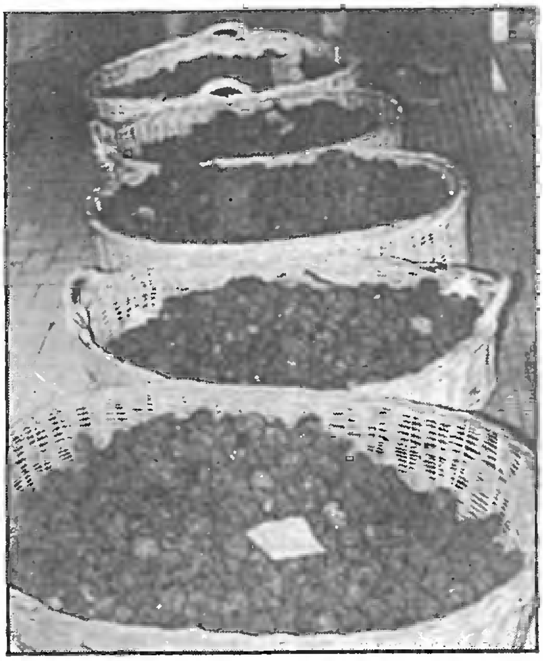


Figure 7. A Truffle market in France.

A group of Oregon trufflateurs has been attempting to grow the Oregon White Truffle, *Tuber gibbossum.* Douglas fir seedlings have been inoculated with mycelium from this native species and planted in plots similar to Christmas tree farms. Several years passed before the harvests began. However, since Oregon White Truffles were naturally occurring nearby, whether or not the inoculation process actually caused the truffles to form is unclear.

Mycorrhizal mushrooms in Europe have suffered a radical decline in years of late while the saprophytic mushrooms have increased in numbers. The combined effects of acid rain and other industrial pollutants, even the disaster at Chernobyl, have been suggested to explain the sudden decline of both the quantity and diversity of wild mycorrhizal mushrooms. Most mycologists believe the sudden availability of dead wood is responsible for the comparative increase in the numbers of saprophytic mushrooms. The decline in Europe portends, in a worst case scenario, a total ecological collapse of the mycorrhizal community. In the past ten years, the diversity of the mycorrhizal mushrooms in Europe has fallen by more than 50%! Some species, such as the Chanterelle, have all but disappeared from regions in the Netherlands, where it was abundant only 20 years ago. (See Arnolds, 1992; Leck, 1991). Many biologists view these mushrooms as indicator species, the first domino to fall in a series leading to the failure of the forest's life-support systems.

One method for inoculating mycorrhizae calls for the planting of young seedlings near the root zones of proven mushroom-producing trees. The new seedlings acclimate and become "infected" with the mycorrhizae of a neighboring, parent tree. In this fashion, a second generation of trees carrying the mycorrhizal fungus is generated. After a few

Figure 8. Scanning electron micrograph of an emerging root tip being mycorrhized by mushroom mycelium.

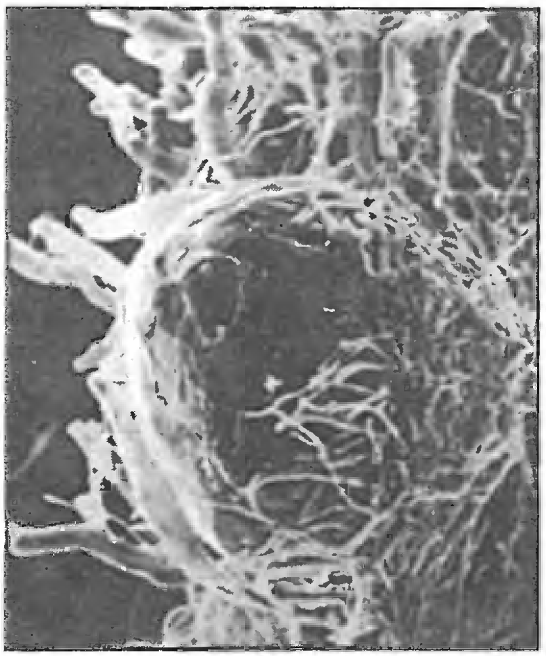


Figure 9. Scanning electron micrograph of mycelium encasing the root of a tree after mycorrhization.

years, the new trees are dug up and replanted into new environments. This method has had the longest tradition of success in Europe.

Another approach, modestly successful, is to dip the exposed roots of seedlings into water enriched with the spore mass of a mycorrhizal candidate. First, mushrooms are gathered from the wild and soaked in water. Thousands of spores are washed off of the gills resulting in an enriched broth of inoculum. A spore-mass slurry coming from several mature mushrooms and diluted into a 5-gallon bucket can inoculate a hundred or more seedlings. The concept is wonderfully simple. Unfortunately, success is not guaranteed.

Broadcasting spore mass onto the root zones of likely candidates is another avenue that costs little in time and effort. Habitats should be selected on the basis of their parallels in nature. For instance, Chanterelles can be found in oak forests of the midwest and in Douglas fir forests of the west. Casting spore mass of Chanterelles into forests similar to those where Chanterelles proliferate is obviously the best choice. Although the success rate is not high, the rewards are well worth the minimum effort involved. Bear in mind that tree roots confirmed to be mycorrhized with a gourmet mushroom will not necessarily result in harvestable mushrooms. Fungi and their host trees may have long associations without the appearance of edible fruitbodies. (For more information, consult Fox (1983)).

On sterilized media, most mycorrhizal mushrooms grow slowly, compared to the saprophytic mushrooms. Their long evolved dependence on root by-products and complex soils makes media preparation inherently more complicated. Some mycorrhizal species, like *Pisolithus tinctorius*, a puffball favoring pines, grow quite readily on sterilized media. A major industry has evolved providing foresters with seedlings inoculated with this fungus. Mycorrhized seedlings are healthier and grow faster than non-mycorrhized ones. Unfortunately, the gourmet mycorrhizal mushroom species do not fall into the readily cultured species category. The famous Matsutake (*Tricholoma magnivelare*) may take weeks before its mycelium fully colonizes the medium on a single petri dish! Unfortunately, this rate of growth is the rule rather than the exception with the majority of gourmet mycorrhizal species.

Chanterelles are one of the most popularly collected wild mushrooms. In the Pacific Northwest of North America the harvesting of Chanterelles has become a controversial, multi-million dollar business. Like Matsutake, Chanterelles (*Cantharellus cibarius*) also form mycorrhizal associations with trees. Additionally, they demonstrate a unique interdependence on soil yeasts. This type of mycorrhizal relationship makes tissue culture most difficult. *At least* three organisms must be cultured simultaneously: the host tree, the mushroom, and soil yeasts. A red soil yeast, *Rhodotorula glutinis*, is crucial in stimulating spore germination. The Chanterelle life cycle may have more dimensions of biological complexity. Currently, no one has grown Chanterelles to the fruitbody stage under laboratory conditions. Not only do other microorganisms play essential roles, the timing of their introduction appears critical to success in the mycorrhizal theater.

Senescence occurs with both saprophytic and mycorrhizal mushroom species. Often the first sign of senescence is not the inability of mycelium to grow vegetatively, but the loss of the formation of the sexually reproducing organ: the mushroom. Furthermore, the slowness from sowing the mycelium to the final stages of harvest confounds the quick feed-back all cultivators need to refine their techniques. Thus, experiments trying to mimic how Chanterelles or Matsutake grow may take 20-40 years each, the age the trees must be to support healthy, fruiting colonies of these prized fungi. Faster methods are clearly desirable, but presently only the natural model has shown any clue to success.

Given the huge hurdle of time for honing laboratory techniques, I favor the "low-tech" approach of planting trees adjacent to known producers of Chanterelles, Matsutake, Truffles and Boletes. After several years, the trees can be uprooted, inspected for mycorrhizae, and replanted in new environments. The value of the contributing forest can then be viewed, not in terms of board feet of lumber, but in terms of its ability for creating satellite, mushroom/tree colonies. When industrial or suburban development threatens entire forests, and is unavoidable, future-oriented foresters may consider the removal of the mycorrhizae as a last-ditch effort to salvage as many mycological communities as possible by simple transplantation techniques, although on a much grander scale.

Until laboratory techniques evolve to establish a proven track record of successful marriages that result in harvestable crops, I hesitate to recommend mycorrhizal mushroom cultivation as an economic endeavor. Mycorrhizal cultivation pales in comparison to the predictability of growing saprophytic mushrooms like Oyster and Shiitake. The industry simply needs the benefit of many more years of mycological research to better decipher the complex models of mycorrhizal mushrooms.

Figure 10. Oyster and Honey Mushrooms growing on a stump.

Parasitic Mushrooms: Blights of the Forest?

Parasitic fungi have been the bane of foresters. They do immeasurable damage to the health of resident tree species, but in the process, create new habitats for many other organisms. Although the ecological damage caused by parasitic fungi is well understood, we are only just learning of their importance in the forest ecosystem. Comparatively few mushrooms are true parasites.

Parasites live off a host plant, endangering the host's health as it grows. Of all the parasitic mushrooms that are edible, the Honey Mushrooms, *Armillaria mellea*, are the best known. One of these Honey Mushrooms, known as *Armillaria bulbosa*, made national headlines when scientists reported finding a single colony covering 37 acres, weighing at least 220,000 lbs. with an estimated age of 1500 years! With the exception of the trembling Aspen forests of Colorado, this fungus is the largest-known, living organism on the planet. And, it is a marauding parasite!

In the past, a parasitic fungus has been looked upon as being biologically evil. This

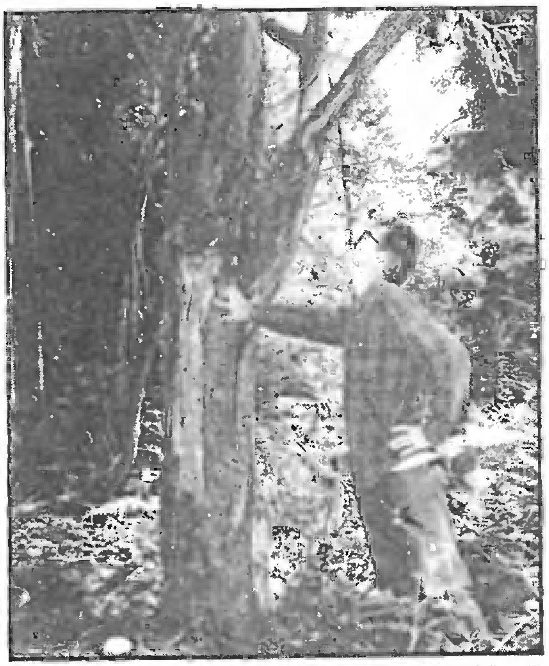


Figure 11. Intrepid amateur mycologist Richard Gaines points to a parasitic fungus attacking Yew

view is rapidly changing as science progresses. A new parasitic fungus attacking the Yew tree has been recently discovered by Montana State University researchers. This new species is called *Taxomyces andreanae* for one notable feature: it produces minute quantities of the potent anti-carcinogen taxol, a proven shrinker of breast cancer. (Stone, 1993). If this new fungus can be grown in sufficient quantities in liquid culture, the potential value of the genome of parasitic fungi takes on an entirely new dimension.

Many saprophytic fungi can be weakly parasitic in their behavior, especially if a host tree is dying from other causes. These can be called *facultative* parasites: saprophytic fungi activated by favorable conditions to behave parasitically. Some parasitic fungi continue to grow long after their host has died. Oyster mushrooms (*Pleurotus ostreatus*) are classic saprophytes, although they are frequently found on dying cottonwood, oak, poplar, birch, maple and alder trees. These appear to be operating parasitically when they are only exploiting a rapidly evolving ecological niche.

Many parasitic fungi are microfungi and are barely visible to the naked eye. In mass, they cause the formation of cankers and shoot blights. Often their preeminence in a middle-aged forest is symptomatic of other imbalances within the ecosystem. Acid rain, ground water pollution, insect damage, and loss of protective habitat all are contributing factors unleashing parasitic fungi. After a tree dies, from parasitic fungi or other causes, saprophytic fungi come into play.

Saprophytic Mushrooms: The Decomposers

Most of the gourmet mushrooms are saprophytic, wood-decomposing fungi. These saprophytic fungi are the premier recyclers on the planet. The filamentous mycelial network is designed to weave between and through the cell walls of plants. The enzymes and acids they secrete degrade large molecular complexes into simpler compounds. All ecosystems depend upon fungi's ability to decompose organic plant matter soon after it is rendered available. The end result of their activity is the return of carbon, hydrogen, nitrogen and minerals back into the ecosystem in forms usable to plants, insects and other organisms. As decomposers, they can be separated into three key groups. Some mushroom species cross over from one category to another depending upon prevailing conditions.

Primary Decomposers: These are the

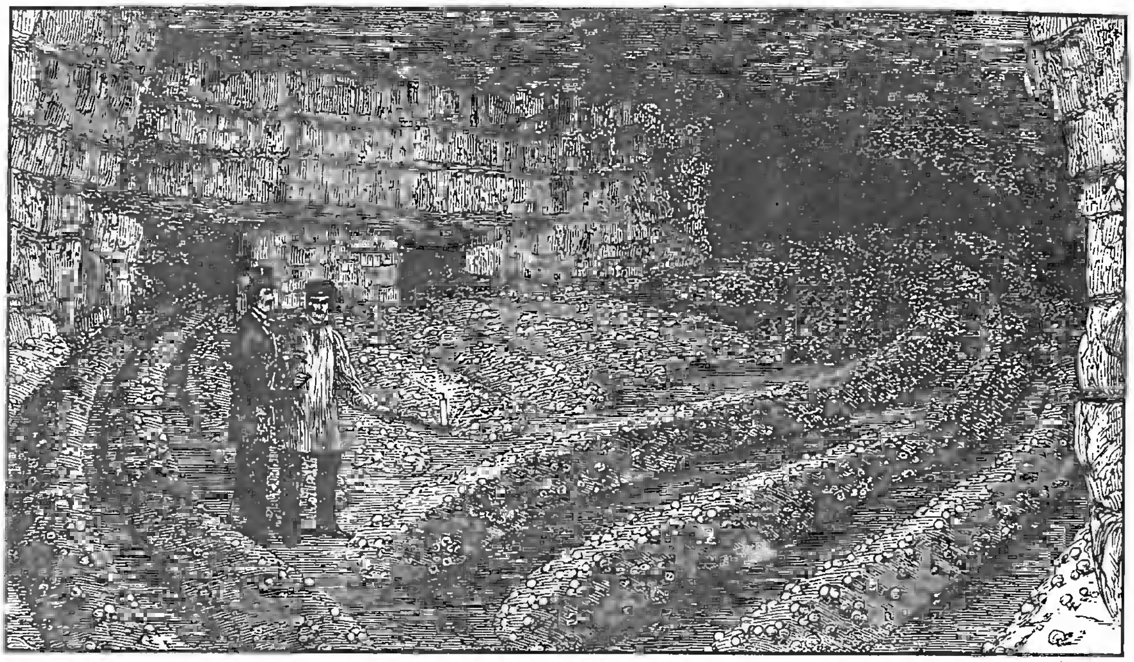


Figure 12. The cultivation of the Button Mushroom, a secondary decomposer, in caves near Paris in July of 1868. Note candle used for illumination. (From Robinson's *Mushroom Culture*, 1885, David Mc Kay Publishers, Philadelphia).

fungi first to capture a twig, a blade of grass, a chip of wood, a log or stump. Primary decomposers are typically fast-growing, sending out ropey strands of mycelium that quickly attach to and decompose plant tissue. Most of the decomposers degrade wood. Hence, the majority of these saprophytes are woodland species, such as Oyster mushrooms (*Pleurotus* species), Shiitake (*Lentinula edodes*) and King Stropharia (*Stropharia rugoso-annulata*). However, each species has developed specific sets of enzymes to break down lignin-cellulose, the structural components of most plant cells. Once the enzymes of one mushroom species have broken down the lignin-cellulose to its fullest potential, other saprophytes utilizing their own repertoire of enzymes can reduce this material even further.

Secondary Decomposers: These mushrooms rely on the previous activity of other fungi to partially break down a substrate to a state wherein they can thrive. Secondary decomposers typically grow from composted material. The actions of other fungi, actinomycetes, bacteria and yeasts all operate within a compost. As plant residue is degraded by these microorganisms, the mass, structure and composition of the compost is reduced. Heat, carbon dioxide, ammonia and other gases are emitted as by-products of the composting process. Once these microorganisms (especially actinomycetes) have completed their life cycles, the compost is susceptible to invasion by a select secondary decomposer. A classic example of a secondary decomposer is the White Button Mushroom, *Agaricus brunnescens*, the most commonly cultivated mushroom.* Another example is *Stropharia ambigua* which invades outdoor mushroom beds after wood chips have been first decomposed by a primary saprophyte.

Tertiary Decomposers: An amorphous group, the fungi represented by this group are typically soil dwellers. They survive in habitats that are years in the making from the activity of the primary and secondary decomposers. Fungi existing in these reduced substrates are remarkable in that the habitat appears inhospitable for most other mushrooms. A classic example of a tertiary decomposer is *Aleuria aurantia,* the Orange Peel Mushroom. This complex group of fungi often pose unique problems to would-be cultivators. *Panaeolus subbalteatus* is yet another example. Although one can grow it on composted substrates, this mushroom has the reputation of growing prolifically in the discarded compost from Button mushroom farms. Other tertiary decomposers include species of *Conocybe, Agrocybe, Pluteus* and some *Agaricus* species.

The floor of a forest is constantly being replenished by new organic matter. Primary, secondary and tertiary decomposers can all occupy the same location. In the complex environment of the forest floor, a "habitat" can actually be described as the overlaying of several habitats mixed into one. And, over time, as each habitat is being transformed, successions of mushrooms occur. This model becomes infinitely complex when taking into account the inter-relationships of not only the fungi to one another, but the fungi to other micro-organisms (yeasts, bacteria, protozoa), plants, insects and mammals.

Primary and secondary decomposers afford the most opportunities for cultivation. To select the best species for cultivation, several variables must be carefully matched.

Climate, available raw materials, and the mushroom strains all must interplay for cultivation to result in success. Native species are the best choices when you are designing outdoor mushroom landscapes.

Temperature-tolerant varieties of mushrooms are more forgiving and easier to grow than those which thrive within finite temperature limits. In warmer climates, moisture is typically more rapidly lost, narrowing the opportunity for mushroom growth. Obviously, growing mushrooms outdoors in a desert climate is more difficult than growing mushrooms in moist environments where they naturally abound. Clearly, the site selection of the mushroom habitat is crucial. The more exposed a habitat is to direct mid-day sun, the more difficult it is for mushrooms to flourish.

Many mushrooms actually benefit from indirect sunlight, especially in the northern latitudes. Pacific Northwest mushroom hunters have long noted that mushrooms grow most prolifically, not in the darkest depths of a woodlands, but in environments where shade and dappled sunlight are combined. Sensitivity studies to light have established that various species differ in their optimal response to wave-bands of sunlight. Nevertheless, few mushrooms enjoy prolonged exposure to direct sunlight.

* The cultivation of this mushroom is covered in detail in *The Mushroom Cultivator* (1983) by Stamets & Chilton.

The Global Environmental Shift and The Loss of Species Diversity

Studies in Europe show a frightening loss of species diversity in forestlands, most evident with the mycorrhizal species. Many mycologists fear many mushroom varieties, and even species, will soon become extinct. As the mycorrhizal species decline in both numbers and variety, the populations of saprophytic and parasitic fungi initially rise, a direct result of the increased availability of dead wood debris. However, as woodlots are burned and replanted, the complex mosaic of the natural forest is replaced by a highly uniform, mono-species landscape. Because the replanted trees are nearly identical in age, the cycle of debris replenishing the forest floor is interrupted. This new "ecosystem" cannot support the myriad of fungi, insects, small mammals, birds, mosses and flora so characteristic of ancestral forests. In pursuit of commercial forests, the native ecology has been supplanted by a biologically anemic woodlot. This woodlot landscape is barren in terms of species diversity.

With the loss of every ecological niche, the sphere of bio-diversity shrinks. At some presently unknown level, the diversity will fall below the critical mass needed for sustaining a healthy forestland. Once passed, the forest may not ever recover without direct and drastic counter-action: the insertion of multi-age trees, of different species, with varying canopies and undergrowth. Even with such extraordinary action, the complexity of a replanted forest can not match that which has evolved for thousands of years. Little is understood about prerequisite microflora—yeasts, bacteria, micro-fungi—upon which the ancient forests are dependent. As the number of species declines, whole communities of organisms disappear. New associations are likewise limited. If this trend continues, I believe the future of new forests, indeed the planet, is threatened.

Apart from the impact of wood harvest, the health of biologically diverse forests is in increasing jeopardy due to acid rain and other airborne toxins. Eventually, the populations of all fungi—saprophytic and mycorrhizal—suffer as the critical mass of dead trees declines more rapidly than it is replenished. North Americans have already experienced the results of habitat-loss from the European forests. Importation of wild picked mushrooms from Mexico, United States and Canada to Europe has escalated radically in the past twenty years. This increase in demand is not just due to the growing popularity of eating wild mushrooms. It is a direct reflection of the decreased availability of wild mushrooms from regions of the world suffering from ecological shock. The woodlands of North America are only a few decades behind the forests of Europe and Asia.

With the loss of habitat of the mycorrhizal gourmet mushrooms, market demands for gourmet mushrooms should shift to those that can be cultivated. Thus, the pressure on this not-yet renewable resource would be alleviated, and the judicious use of saprophytic fungi by homeowners as well as foresters may well prevent widespread parasitic disease vectors. Selecting and controlling the types of saprophytic fungi occupying these ecological niches can benefit both forester and forestland.

Catastrophia: Nature as a Substrate Supplier

Many saprophytic fungi benefit from catastrophic events in the forests. When hurricane-force winds rage across woodlands, enormous masses of dead debris are generated. The older trees are especially likely to fall. Once the higher canopy is gone, the growth of the younger, lower canopy of trees is triggered by the suddenly available sunlight. The continued survival of young trees is dependent upon the quick recycling of nutrients by the saprophytic fungi.

Every time catastrophes occur—hurricanes, tornadoes, volcanoes, floods, even earthquakes—the resulting dead wood becomes a stream of inexpensive substrate materials. In a sense, the cost of mushroom production is underwritten by natural disasters. Unfortunately, to date, few individuals and communities take advantage of catastrophia as fortuitous events for mushroom culture. However, once the economic value of recycling with gourmet and medicinal mushrooms is clearly understood, and with the increasing popularity of backyard cultivation, catastrophia can be viewed as a positive event, at least in terms of providing new economic opportunities for those who are mycologically astute.

Mushrooms and Toxic Wastes

In heavily industrialized areas, soils are often contaminated with a wide variety of pollutants, particularly petroleum-based compounds, polychlorinated biphenols (PCB's). heavy metals, pesticide-related compounds, and even radioactive wastes. Mushrooms grown in polluted environments can absorb toxins directly into their tissues. As a result,

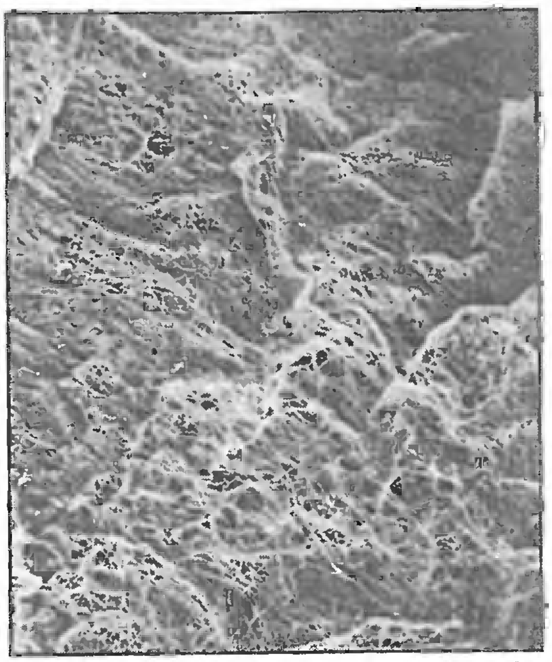


Figure 13. Scanning electron micrograph of the mycelial network.

mushrooms grown in these environments should not be eaten. Recently, a visitor to Ternobyl, a city about 60 miles from Chernobyl, the site of the world's worst nuclear power plant accident, returned to the United States with a jar of pickled mushrooms. The mushrooms were radioactive enough to set off Geiger counter alarms as the baggage was being processed. The mushrooms were promptly confiscated by Customs officials. Unfortunately, most toxins are not so readily detected.

A number of fungi can, however, be used to detoxify contaminated environments, a process called "bioremediation". The white rot fungi (particularly *Phanerochaete chrysosporium*) and brown rot fungi (notably *Gloephyllum* species) are the most widely used. Most of these wood-rotters produce lignin peroxidases and cellulases which have unusually powerful degradative properties. These extracellular enzymes have evolved to break down plant fiber, primarily lignin-cellulose, the structural component in woody plants, into simpler forms. By happenstance, these same enzymes also reduce recalcitrant hydrocarbons and other man-made toxins. Given the number of industrial pollutants that are hydrocarbon-based, fungi are excellent candidates for toxic waste clean-up and are viewed by scientists and government agencies with increasing interest. Current and prospective future uses include the detoxification of PCB (polychlorolbiphenols), PCP (pentachlorophenol), oil, pesticide/herbicide residues, and even are being explored for ameliorating the impact of radioactive wastes.

Bioremediation of toxic waste sites is especially attractive because the environment is treated *in situ.* The contaminated soils do not have to be hauled away, eliminating the extraordinary expense of handling, transportation, and storage. Since these fungi have the ability to reduce complex hydrocarbons into elemental compounds, these compounds pose no threat to the environment. Indeed, these former pollutants could even be considered as "fertilizer", helping rather than harming the nutritional base of soils.

Dozens of bioremediation companies have formed to solve the problem of toxic waste. Most of these companies look to the imperfect fungi. The higher fungi should not be disqualified for bioremediation just because they produce fruitbody. Indeed, this group may hold answers to many of the toxic waste problems. The most vigorous rotters described in this book are the *Ganoderma* and *Pleurotus* mushrooms. However, mushrooms grown from toxic wastes are best not eaten as residual toxins may be concentrated within the mushrooms.

Mushroom Mycelium and Mycofiltration

The mycelium is fabric of interconnected, interwoven strands of cells. A colony can be the size of a half-dollar or many acres. A cubic inch of soil can host up to a mile of mycelium. This organism can be physically separated, and yet behave as one.

The exquisite lattice-like structure of the mushroom mycelium, often referred to as the *mycelial network*, is perfectly designed as a filtration membrane. Each colony extends long, complex chains of cells that fork repeatedly in matrix-like fashion, spreading to geographically defined borders. The mushroom mycelium, being a voracious forager for carbon and nitrogen, secretes extracellular enzymes that unlock organic complexes. The newly freed nutrients are then selectively absorbed directly through the cell walls into the mycelial network.

In the rainy season, water carries nutritional particles through this filtration membrane, including bacteria, which often become a food source for the mushroom mycelium. The resulting downstream effluent is cleansed of not only carbon/nitrogen-rich compounds but also bacteria, in some cases nematodes, and legions of other micro-organisms. Only recently has the classic saprophyte, the voracious Oyster mushroom, been found to be parasitic against nematodes. (See Thorn & Barron, 1984). The extracellular enzymes act like an anesthetic and stun the nematodes, thus allowing the invasion of the mycelium directly into their immobilized bodies.

The use of mycelium as a mycofilter is currently being studied by this author in the removal of biological contaminants from surface water passing directly into sensitive watersheds. By placing sawdust implanted with mushroom mycelium in drainage basins downstream from farms raising livestock, the mycelium acts as a sieve which traps fecal bacteria and ameliorates the impact of a farm's nitrogen-rich outflow into aquatic ecosystems. This concept is incorporated into an integrated farm model and explored in greater detail in Chapter 5: Permaculture with a Mycological Twist.

Translating value. Oregon. Khmer buyers sort a picker's matsutake to determine the price. Economic diversity enables capitalism but also undermines its hegemony.

10 Salvage Rhythms: Business in Disturbance

A COLLEAGUE WHO STUDIES PEOPLE AND FORESTS IN Borneo told me the following story: The community he worked with lived in and around a great forest. A timber company came and cut down the forest. When the trees were gone, the company left, leaving a pile of disintegrating machines. The residents could no longer make a living either from the forest or from the company. They took apart the machines and sold the metal as scrap.[1]

The story, for me, encapsulates the ambivalence of salvage: On the one hand, I am full of admiration for the people who figured out how to survive despite the destruction of their forest. On the other hand, I can't help but worry when the scrap metal will run out, and whether there will be enough other stuff in the ruins to make continuing survival possible. And while not all of us enact such a literal figuration of living in ruins, we mostly do have to work within our disorientation and distress to negotiate life in human-damaged environments. We follow salvage rhythms, whether of the market for scrap or of the entangled histories of foraging for matsutake mushrooms. By "rhythms," I mean forms of temporal coordination. Without the singular, forward pulse of progress, the unregularized coordination of salvage is what we have.

During most of the twentieth century, many people—perhaps particularly Americans—thought that business carried forward the pulse of progress. Business was always getting bigger. It seemed to be increasing the world's wealth. It was effectively reshaping the world according to its goals and needs, so that people could be empowered by money and things for use and commercial exchange. All it seemed people had to do—even ordinary people without investment capital—was to tie their own rhythms to the forward pulse of business, and they too would move forward. This worked through scalability; people and nature could join progress by becoming units in its algorithm of expansion. Advancement, ever expanding, would move through them in tandem.

All of that now seems increasingly strange. Yet experts in the business world seem to be unable to do without this apparatus for making knowledge. The economic system is presented to us as a set of abstractions requiring assumptions about participants (investors, workers, raw materials) that take us right into twentieth-century notions of scalability and expansion as progress. Seduced by the elegance of these abstractions, few think it important to take a closer look at the world the economic system supposedly organizes. Ethnographers and journalists give us reports of survival, flourishing, and distress, here and there. Yet there is a rift between what experts tell us about economic growth, on the one hand, and stories about life and livelihood, on the other. This is not helpful. It is time to reimbue our understanding of the economy with arts of noticing.

Thinking through salvage rhythms changes our vision. Industrial work no longer charts the future. Livelihoods are various, cobbled together, and often temporary. People come to them for diverse reasons, and only rarely because they offer the stable wages-and-benefits packages of twentieth-century dreams. I have suggested we watch patches of livelihood come into being as assemblages. Participants come with varied agendas, which do their small part in guiding world-making projects. For Open Ticket mushroom hunters, these include surviving war trauma and negotiating a working relationship with U.S. citizenship. Such projects mobilize commercial foraging, drawing pickers into the forest to follow "mushroom fever." Despite differences across these projects, boundary objects have formed—and particularly a commitment to what the pickers call freedom. Through such imagined common ground, commercial picking gains coherence as a scene—and a gathering becomes a happening. Multidirectional histories become possible through its emergent qualities. Without top-down discipline or synchronization, and without expectations of progress, livelihood patches help constitute the global political economy.

In collecting goods and people from around the world, capitalism itself has the characteristics of an assemblage. However, it seems to me that capitalism *also* has characteristics of a machine, a contraption limited to the sum of its parts. This machine is not a total institution, which we spend our lives inside; instead, it translates across living arrangements, turning worlds into assets. But not just any translation can be accepted into capitalism. The gathering it sponsors is not open-ended. An army of technicians and managers stand by to remove offending parts—and they have the power of courts and guns. This does not mean that the machine has a static form. As I argued in tracing the history of Japanese-U.S. trade relations, new forms of capitalist translation come into being all the time. Indeterminate encounters matter in shaping capitalism. Yet it is not a wild profusion. Some commitments are sustained, through force.

Two have been particularly important for my thinking in this book. First, alienation is that form of disentanglement that allows the making of capitalist assets. Capitalist commodities are removed from their life-worlds to serve as counters in the making of further investments. Infinite needs are one result; there is no limit on how many assets investors want. Thus, too, alienation makes possible accumulation—the amassing of investment capital, and this is the second of my concerns. Accumulation is important because it converts ownership into power. Those with capital can overturn communities and ecologies. Meanwhile, because capitalism is a system of commensuration, capitalist value forms flourish even across great circuits of difference. Money becomes investment capital, which can produce more money. Capitalism is a translation machine for producing capital from all kinds of livelihoods, human and not human.[2]

My ability to think with patches and translations draws from a robust body of scholarship on such issues, particularly that emerging from feminist anthropology. Feminist scholars have shown that class formation is also cultural formation: the origin of my patches.[3] They also pioneered the study of transactions across heterogeneous landscapes: my translations.[4] If I have added to the conversation, it is in drawing attention to livelihoods that are simultaneously inside and outside of capitalism. Rather than focus our attention only on the capitalist imaginary, with its disciplined workers and savvy managers, I have tried to show precarious living in scenes that both use and refuse capitalist governance. Such assemblages tell us of what's left, despite capitalist damage.

Before they arrive in the hands of consumers, most commodities journey in and out of capitalist formations. Think about your cell phone. Deep in its circuitry, you find coltan dug by African miners, some of them children, who scramble into dark holes without thought of wages or benefits. No companies send them; they are doing this dangerous work because of civil war, displacement, and loss of other livelihoods, owing to environmental degradation. Their work is hardly what experts imagine as capitalist labor; yet their products enter your phone, a capitalist commodity.[5] Salvage accumulation, with its apparatus of translation, converts the ores they dig into assets legible to capitalist business. And what of my computer? After its short useful life (as I surely must replace it with a newer model), perhaps I will donate it to a charitable organization. What happens to such computers? It seems they are burned for potential components, and children indeed, following salvage rhythms, get to pick them apart for copper and other metals.[6] Commodities often finish their lives in salvage operations for the making of other commodities, to be recouped again for capitalism through salvage accumulation. If we want our theories of the "economic system" to have anything to do with livelihood practices, we had better take note of such salvage rhythms.

The challenges are enormous. Salvage accumulation reveals a world of difference, where oppositional politics does not fall easily into utopian plans for solidarity. Every livelihood patch has its own history and dynamics, and there is no automatic urge to argue *together*, across the viewpoints emerging from varied patches, about the outrages of accumulation and power. Since no patch is "representative," no group's struggles, taken alone, will overturn capitalism. Yet this is not the end of politics. Assemblages, in their diversity, show us what later I call the "latent commons," that is, entanglements that might be mobilized in common cause. Because collaboration is always with us, we can maneuver within its possibilities. We will need a politics with the strength of diverse and shifting coalitions—and not just for humans.

The business of progress depended on conquering an infinitely rich nature through alienation and scalability. If nature has turned finite, and even fragile, no wonder entrepreneurs have rushed to get what they can before the goods run out, while conservationists desperately contrive to save scraps. The next part of this book offers an alternative politics of more-than-human entanglements.

Elusive life. Oregon. The spoor of deer and elk lead pickers to matsutake patches. There, cracks signal a deep-seated mushroom rising through the ground. Tracking means following worldly entanglements.

Interlude
Tracking

MUSHROOM TRACKS ARE ELUSIVE AND ENIGMATIC; following them takes me on a wild ride—trespassing every boundary. Things get even stranger when I move out of commerce into Darwin's "entangled bank" of multiple life forms.[1] Here, the biology we thought we knew stands on its head. Entanglement bursts categories and upends identities.

Mushrooms are the fruiting bodies of fungi. Fungi are diverse and often flexible, and they live in many places, ranging from ocean currents to toenails. But many fungi live in the soil, where their thread-like filaments, called hyphae, spread into fans and tangle into cords through the dirt. If you could make the soil liquid and transparent and walk into the ground, you would find yourself surrounded by nets of fungal hyphae. Follow fungi into that underground city, and you will find the strange and varied pleasures of interspecies life.[2]

Many people think fungi are plants, but they are actually closer to animals. Fungi do not make their food from sunlight, as plants do. Like animals, fungi must find something to eat. Yet fungal eating is often generous: It makes worlds for others. This is because fungi have extracellular digestion. They excrete digestive acids outside their bodies to break down their food into nutrients. It's as if they had everted stomachs, digesting food outside instead of inside their bodies. Nutrients are then absorbed into their cells, allowing the fungal body to grow—but also other species' bodies. The reason there are plants growing on dry land (rather than just in water) is that over the course of the earth's history fungi have digested rocks, making nutrients available for plants. Fungi (together with bacteria) made the soil in which plants grow. Fungi also digest wood. Otherwise, dead trees would stack up in the forest forever. Fungi break them down into nutrients that can be recycled into new life. Fungi are thus world builders, shaping environments for themselves and others.

Some fungi have learned to live in intimate associations with plants, and given enough time to adjust to the interspecies relations of a place, most plants enter into associations with fungi. "Endophytic" and "endomycorrhizal" fungi live inside plants. Many do not have fruiting bodies; they gave up sex millions of years ago. We are likely never to see these fungi unless we peer inside plants with microscopes, yet most plants are thick with them. "Ectomycorrhizal" fungi wrap themselves around the outsides of roots as well as penetrating between their cells. Many of the favorite mushrooms of people around the world—porcini, chanterelles, truffles, and, indeed, matsutake—are the fruiting bodies of ectomycorrhizal plant associates. They are so delicious, and so difficult for humans to manipulate, because they thrive together with host trees. They come into being only through interspecies relations.

The term "mycorrhiza" is assembled from Greek words for "fungus" and "root"; fungi and plant roots become intimately entangled in mycorrhizal relations. Neither the fungus nor the plant can flourish without the activity of the other. From the fungal perspective, the goal is to get a good meal. The fungus extends its body into the host's roots to siphon off some of the plant's carbohydrates through specialized interface structures, made in the encounter. The fungus depends on this food, yet it is not entirely selfish. Fungi stimulate plant growth, first, by getting plants more water, and, second, by making the nutrients of extracellular digestion available to plants. Plants get calcium, nitrogen, potassium, phosphorus, and other minerals through mycorrhiza. Forests, according to researcher Lisa Curran, occur only because of ectomycorrhizal fungi.[3] By leaning on fungal companions, trees grow strong and numerous, making forests.

Mutual benefits do not lead to perfect harmony. Sometimes the fungus parasitizes the root in one phase of its life cycle. Or, if the plant has lots of nutrients, it may reject the fungus. A mycorrhizal fungus without a plant collaborator will die. But many ectomycorrhizas are not limited to one collaboration; the fungus forms a network across plants. In a forest, fungi connect not just trees of the same species, but often many species. If you cover a tree in the forest, depriving its leaves of light and thus food, its mycorrhizal associates may feed it from the carbohydrates of other trees in the network.[4] Some commentators compare mycorrhizal networks to the Internet, writing of the "woodwide web." Mycorrhizas form an infrastructure of interspecies interconnection, carrying information across the forest. They also have some of the characteristics of a highway system. Soil microbes that would otherwise stay in the same place are able to travel in the channels and linkages of mycorrhizal interconnection. Some of these microbes are important for environmental remediation.[5] Mycorrhizal networks allow forests to respond to threats.

Why has the world-building work of fungi received so little appreciation? Partly, this is because people can't venture underground to see the amazing architecture of the underground city. But it is also because until quite recently many people—perhaps especially scientists—imagined life as a matter of species-by-species reproduction. The most important interspecies interactions, in this worldview, were predator-prey relations in which interaction meant wiping each other out. Mutualistic relations were interesting anomalies, but not really necessary to understand life. Life emerged from the self-replication of each species, which faced evolutionary and environmental challenges on its own. No species needed another for its continuing vitality; it organized itself. This self-creation marching band drowned out the stories of the underground city. To recover those underground stories, we might reconsider the species-by-species worldview, and the new evidence that has begun to transform it.

When Charles Darwin proposed a theory of evolution through natural selection in the nineteenth century, he had no explanation for heritability. Only the recovery in 1900 of Gregor Mendel's work on genetics suggested a mechanism by which natural selection could produce its effects. In the twentieth century, biologists combined genetics and evolution and created the "modern synthesis," a powerful story about how species come into being through genetic differentiation. The early-twentieth-century discovery of chromosomes, structures within cells that carry genetic information, gave palpability to the story. Units of heredity—genes—were located on chromosomes. In sexually reproducing vertebrates, a special line of "germ cells" was found to conserve the chromosomes that give rise to the next generation. (Human sperm and eggs are germ cells.) Changes in the rest of the body—even genetic changes—should not be transmitted to offspring as long as they do not affect the germ cells' chromosomes. Thus the self-replication of the species would be protected from the vicissitudes of ecological encounter and history. As long as the germ cells were unaffected, the organism would remake itself, extending species continuity.

This is the heart of the species self-creation story: Species reproduction is self-contained, self-organized, and removed from history. To call this the "modern synthesis" is quite right in relation to the questions of modernity that I discussed in terms of scalability. Self-replicating things are models of the kind of nature that technical prowess can control: they are modern things. They are interchangeable with each other, because their variability is contained by their self-creation. Thus, they are also scalable. Inheritable traits are expressed at multiple scales: cells, organs, organisms, populations of interbreeding individuals, and, of course, the species itself. Each of these scales is another expression of self-enclosed genetic inheritance, and thus they are neatly nested and scalable. As long as they are all expressions of the same traits, research can move back and forth across these scales without friction. Some hint of coming problems appeared in this paradigm's excesses: when researchers took scalability literally, they produced bizarre new stories of the gene in charge of everything. Genes for criminality and creativity were proposed, sliding freely across scales from chromosome to social world. "The selfish gene," in charge of evolution, required no collaborators. Scalable life, in these versions, captured genetic inheritance in a self-enclosed and self-replicating modernity, indeed, Max Weber's iron cage.

The discovery of the stability and self-replicating properties of DNA in the 1950s was the jewel in the crown of the modern synthesis—but also the opening to its undoing. DNA, with associated proteins, is the material of chromosomes. The chemical structure of its double helix strands is both stable and, amazingly, able to replicate exactly on a newly built strand. What a model for self-contained replication! The replication of DNA was mesmerizing; it formed an icon for modern science itself, which requires the replication of results, and thus research objects that are stable and interchangeable across experimental iterations, that is, without history. The results of the replication of DNA can be tracked at every biological scale (protein, cell, organ, organism, population, species). Biological scalability was given a mechanism, strengthening the story of thoroughly modern life—life ruled by gene expression and isolated from history.

Yet DNA research has led in unexpected directions. Consider the trajectory of evolutionary developmental biology. This field was one of the many that emerged from the DNA revolution; it studies genetic mutation and expression in the development of organisms, and the implications of this for speciation. In studying development, however, researchers could not avoid the history of encounters between an organism and its environment. They found themselves in conversation with ecologists, and suddenly they realized they had evidence for a type of evolution that had not been expected by the modern synthesis. In contrast to the modern orthodoxy, they found that many kinds of environmental effects could be passed on to offspring, through a variety of mechanisms, some affecting gene expression and others influencing the frequency of mutations or the dominance of varietal forms.[6]

One of their most surprising findings was that many organisms develop only through interactions with other species. A tiny Hawaiian squid, *Euprymna scolopes*, has become a model for thinking about this process.[7] The "bob-tailed squid" is known for its light organ, through which it mimics moonlight, hiding its shadow from predators. But juvenile squid do not develop this organ unless they come into contact with one particular species of bacteria, *Vibrio fischeri*. The squid are not born with these bacteria; they must encounter them in the seawater. Without them, the light organ never develops. But perhaps you think light organs are superfluous. Consider the parasitic wasp *Asobara tabida*. Females are completely unable to produce eggs without bacteria of the genus *Wolbachia*.[8] Meanwhile, larvae of the Large Blue butterfly *Maculinea arion* are unable to survive without being taken in by an ant colony.[9] Even we proudly independent humans are unable to digest our food without helpful bacteria, first gained as we slide out of the birth canal. Ninety percent of the cells in a human body are bacteria. We can't do without them.[10]

As biologist Scott Gilbert and his colleagues write, "Almost all development may be codevelopment. By codevelopment we refer to the ability of the cells of one species to assist the normal construction of the body of another species."[11] This insight changes the unit of evolution. Some biologists have begun to speak of the "hologenome theory of evolution," referring to the complex of organisms and their symbionts as an evolutionary unit: the "holobiont."[12] They find, for example, that associations between particular bacteria and fruit flies influence fruit fly mating choice, thus shaping the road to the development of a new species.[13] To add the importance of development, Gilbert and his colleagues use the term "symbiopoiesis," the codevelopment of the holobiont. The term contrasts their findings with an earlier focus on life as internally self-organizing systems, self-formed through "autopoiesis." "More and more," they write, "symbiosis appears to be the 'rule,' not the exception. . . . Nature may be selecting 'relationships' rather than individuals or genomes."[14]

Interspecies relations draw evolution back into history because they depend on the contingencies of encounter. They do not form an internally self-replicating system. Instead, interspecies encounters are always events, "things that happen," the units of history. Events can lead to relatively stable situations, but they cannot be counted on in the way self-replicating units can; they are always framed by contingency and time. History plays havoc with scalability. The only way to create scalability is to repress change and encounter. If they can't be repressed, the whole relation across scales must be rethought. When British conservationists tried to save the Large Blue butterfly, mentioned above, they could not assume that a mating population could by itself reproduce the species, although, according to the modern synthesis, populations are formed from individuals formed by genes. They could not leave out the ants without which the larvae cannot survive.[15] Large Blue butterfly populations are thus not a scalable effect of the butterflies' DNA. They are nonscalable sites of interspecies encounter. This is a problem for the modern synthesis, because population genetics was from the early twentieth century at the core of evolution-without-history. Might population science need to step aside for an emergent multispecies historical ecology? Might the arts of noticing I discuss be at its core?[16]

Reintroducing history into evolutionary thinking has already begun at other biological scales. The cell, once an emblem of replicable units, turns out to be the historical product of symbiosis among free-living bacteria.[17] Even DNA turns out to have more history in its amino-acid sequences than once thought. Human DNA is part virus; viral encounters mark historical moments in making us human.[18] Genome research has taken up the challenge of identifying encounter in the making of DNA. Population science cannot avoid history for much longer.[19]

Fungi are ideal guides. Fungi have always been recalcitrant to the iron cage of self-replication. Like bacteria, some are given to exchanging genes in nonreproductive encounters ("horizontal gene transfer"); many also seem averse to keeping their genetic material sorted out as "individuals" and "species," not to speak of "populations." When researchers studied the fruiting bodies of what they thought of as a species, the expensive Tibetan "caterpillar fungus," they found many species entangled together.[20] When they looked into the filaments of *Armillaria* root rot, they found genetic mosaics that confused the identification of an individual.[21] Meanwhile, fungi are famous for their symbiotic attachments. Lichen are fungi living together with algae and cyanobacteria. I have been discussing fungal collaborations with plants, but fungi live with animals as well. For example, *Macrotermes* termites digest their food only through the help of fungi. The termites chew up wood, but they cannot digest it. Instead, they build "fungus gardens" in which the chewed-up wood is digested by *Termitomyces* fungi, producing edible nutrients. Researcher Scott Turner points out that, while you might say that the termites farm the fungus, you could equally say that the fungus farms the termites. *Termitomyces* uses the environment of the termite mound to outcompete other fungi; meanwhile, the fungus regulates the mound, keeping it open, by throwing up mushrooms annually, creating a colony-saving disturbance in termite mound-building.[22]

Our metaphorical language (here termite "farming") sometimes gets in the way and sometimes throws up unexpected insights. One of the most common metaphors in talk of symbiosis is "outsourcing." You could say the termites outsource their digestion to fungi, or, alternatively, that the fungi outsource food gathering and niche building to termites. There are lots of things wrong with comparing biological processes to contemporary business arrangements, too many, indeed, to catalogue. But perhaps there is one insight here. As in capitalist supply chains, these chains of engagement are not scalable. Their components cannot be reduced to self-replicating interchangeable objects, whether firms or species. Instead, they require attention to the histories of encounter that maintain the chain. Natural history description, rather than mathematical modeling, is the necessary first step—as in the economy. Radical curiosity beckons. Perhaps an anthropologist, trained in one of the few remaining sciences that values observation and description, might come in handy.

WHEN KATO-SAN INTRODUCED ME TO THE WORK HE was doing for the prefectural forest-research service to restore the forest, I was shocked. As an American tutored in wilderness sensibilities, I thought forests were best at restoring themselves. Kato-san disagreed: If you want matsutake in Japan, he explained, you must have pine, and if you want pine, you must have human disturbance. He was supervising work to remove broadleaf trees from the hillside he showed me. Even the topsoil had been carted away, and the steep slope now looked gouged and bare to my American eyes. "What about erosion?" I asked. "Erosion is good," he answered. Now I was really startled. Isn't erosion, the loss of soil, always bad? Still, I was willing to listen: pine flourishes on mineral soils, and erosion uncovers them.

Working with forest managers in Japan changed how I thought about the role of disturbance in forests. Deliberate disturbance to revitalize forests surprised me. Kato-san was not planting a garden. The forest he hoped for would have to grow itself. But he wanted to help it along by creating a certain kind of mess: a mess that would advantage pine.

Kato-san's work engages with a popular and scientific cause: restoring *satoyama* woodlands. Satoyama are traditional peasant landscapes, combining rice agriculture and water management with woodlands. The woodlands—the heart of the satoyama concept—were once disturbed, and thus maintained, through their use for firewood and charcoal-making as well as nontimber forest products. Today, the most valuable product of the satoyama woodland is matsutake. To restore woodlands for matsutake encourages a suite of other living things: pines and oaks, understory herbs, insects, birds. Restoration requires disturbance—but disturbance to enhance diversity and the healthy functioning of ecosystems. Some kinds of ecosystems, advocates argue, flourish with human activities.

Ecological restoration programs around the world use human action to rearrange natural landscapes. What distinguishes satoyama revitalization, for me, is the idea that human activities should be part of the forest in the same way as nonhuman activities. Humans, pines, matsutake, and other species should all make the landscape together, in this project. One Japanese scientist explained matsutake as the result of "unintentional cultivation," because human disturbance makes the presence of matsutake more likely—despite the fact that humans are entirely incapable of cultivating the mushroom. Indeed, one could say that pines, matsutake, and humans all cultivate each other unintentionally. They make each other's world-making projects possible. This idiom has allowed me to consider how landscapes more generally are products of *unintentional design*, that is, the overlapping world-making activities of many agents, human and not human. The design is clear in the landscape's ecosystem. But none of the agents have planned this effect. Humans join others in making landscapes of unintentional design.

As sites for more-than-human dramas, landscapes are radical tools for decentering human hubris. Landscapes are not backdrops for historical action: they are themselves active. Watching landscapes in formation shows humans joining other living beings in shaping worlds. Matsutake and pine don't just grow in forests; they make forests. Matsutake forests are gatherings that build and transform landscapes. This part of the book begins with disturbance—and I make disturbance a beginning, that is, an opening for action. Disturbance realigns possibilities for transformative encounter. Landscape patches emerge from disturbance. Thus precarity is enacted in more-than-human sociality.

CHAPTER 2

Tentacular Thinking

Anthropocene, Capitalocene, Chthulucene

We are all lichens.
—Scott Gilbert, "We Are All Lichens Now"

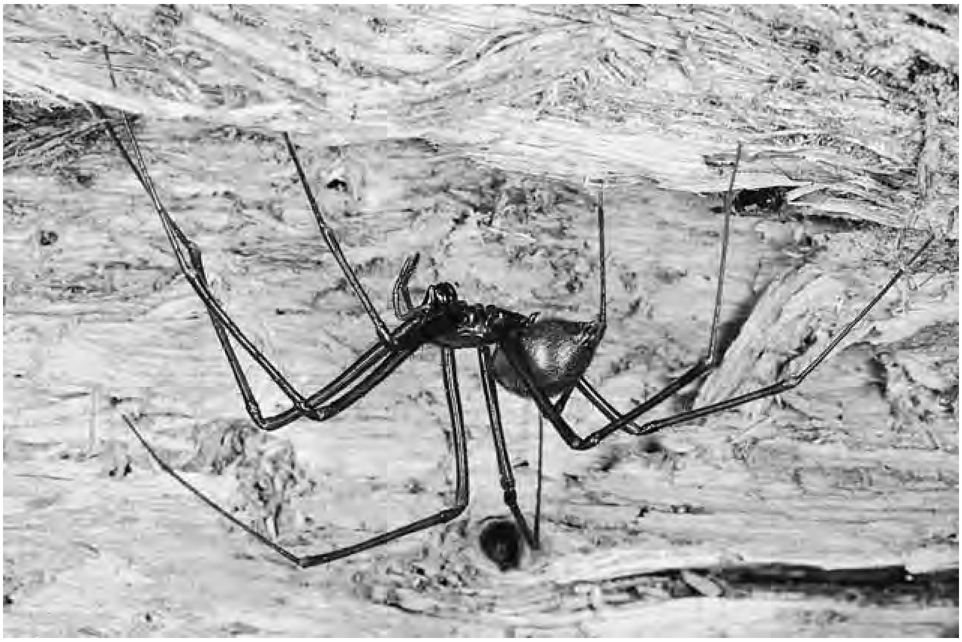
Think we must. We must think.
—Stengers and Despret, *Women Who Make a Fuss*

What happens when human exceptionalism and bounded individualism, those old saws of Western philosophy and political economics, become unthinkable in the best sciences, whether natural or social? Seriously unthinkable: not available to think with. Biological sciences have been especially potent in fermenting notions about all the mortal inhabitants of the earth since the imperializing eighteenth century. *Homo sapiens*—the Human as species, the Anthropos as the human species, Modern Man—was a chief product of these knowledge practices. What happens when the best biologies of the twenty-first century cannot do their job with bounded individuals plus contexts, when organisms plus environments, or genes plus whatever they need, no longer sustain the overflowing richness of biological knowledges, if they ever did? What happens when organisms plus environments can hardly be remembered for the same reasons that even Western-indebted people can no longer figure themselves as individuals and societies of individuals in human-only histories? Surely such a transformative time on earth must not be named the Anthropocene!

In this chapter, with all the unfaithful offspring of the sky gods, with my littermates who find a rich wallow in multispecies muddles, I want to make a critical and joyful fuss about these matters. I want to stay with the trouble, and the only way I know to do that is in generative joy, terror, and collective thinking.

My first demon familiar in this task will be a spider, *Pimoa cthulhu*, who lives under stumps in the redwood forests of Sonoma and Mendocino Counties, near where I live in North Central California.[1] Nobody lives everywhere; everybody lives somewhere. Nothing is connected to everything; everything is connected to something.[2] This spider is in place, has a place, and yet is named for intriguing travels elsewhere. This spider will help me with returns, and with roots and routes.[3] The eight-legged tentacular arachnid that I appeal to gets her generic name from the language of the Goshute people of Utah and her specific name from denizens of the depths, from the abyssal and elemental entities, called chthonic.[4] The chthonic powers of Terra infuse its tissues everywhere, despite the civilizing efforts of the agents of sky gods to astralize them and set up chief Singletons and their tame committees of multiples or subgods, the One and the Many. Making a small change in the biologist's taxonomic spelling, from cthulhu to chthulu, with renamed *Pimoa chthulu* I propose a name for an elsewhere and elsewhen that was, still is, and might yet be: the Chthulucene. I remember that *tentacle* comes from the Latin *tentaculum*, meaning "feeler," and *tentare*, meaning "to feel" and "to try"; and I know that my leggy spider has many-armed allies. Myriad tentacles will be needed to tell the story of the Chthulucene.[5]

The tentacular ones tangle me in SF. Their many appendages make string figures; they entwine me in the poiesis—the making—of speculative fabulation, science fiction, science fact, speculative feminism, *soin de ficelle*, so far. The tentacular ones make attachments and detachments; they ake cuts and knots; they make a difference; they weave paths and consequences but not determinisms; they are both open and knotted in some ways and not others.[6] SF is storytelling and fact telling; it is the patterning of possible worlds and possible times, material-semiotic worlds, gone, here, and yet to come. I work with string figures as a theoretical trope, a way to think-with a host of companions in sympoietic threading, felting, tangling, tracking, and sorting. I work with and in SF as material-semiotic composting, as theory in the mud, as muddle.[7]



2.1. *Pimoa cthulhu*. Photograph by Gustavo Hormiga.

The tentacular are not disembodied figures; they are cnidarians, spiders, fingery beings like humans and raccoons, squid, jellyfish, neural extravaganzas, fibrous entities, flagellated beings, myofibril braids, matted and felted microbial and fungal tangles, probing creepers, swelling roots, reaching and climbing tendrilled ones. The tentacular are also nets and networks, IT critters, in and out of clouds. Tentacularity is about life lived along lines—and such a wealth of lines—not at points, not in spheres. "The inhabitants of the world, creatures of all kinds, human and non-human, are wayfarers"; generations are like "a series of interlaced trails."[8] String figures all.

All the tentacular stringy ones have made me unhappy with posthumanism, even as I am nourished by much generative work done under that sign. My partner Rusten Hogness suggested compost instead of posthuman(ism), as well as humusities instead of humanities, and I jumped into that wormy pile.[9] Human as humus has potential, if we could chop and shred human as Homo, the detumescing project of a self-making and planet-destroying CEO. Imagine a conference not on the Future of the Humanities in the Capitalist Restructuring University, but instead on the Power of the Humusities for a Habitable Multispecies Muddle! Ecosexual artists Beth Stephens and Annie Sprinkle made a bumper sticker for me, for us, for SF: "Composting is so hot!"[10]

The earth of the ongoing Chthulucene is sympoietic, not autopoietic. Mortal Worlds (Terra, Earth, Gaia, Chthulu, the myriad names and powers that are not Greek, Latin, or Indo-European at all)[11] do not make themselves, no matter how complex and multileveled the systems, no matter how much order out of disorder might be produced in generative autopoietic system breakdowns and relaunchings at higher levels of order. Autopoietic systems are hugely interesting—witness the history of cybernetics and information sciences; but they are not good models for living and dying worlds and their critters. Autopoietic systems are not closed, spherical, deterministic, or teleological; but they are not quite good enough models for the mortal SF world. Poiesis is symchthonic, sympoietic, always partnered all the way down, with no starting and subsequently interacting "units."[12] The Chthulucene does not close in on itself; it does not round off; its contact zones are ubiquitous and continuously spin out loopy tendrils. Spider is a much better figure for sympoiesis than any inadequately leggy vertebrate of whatever pantheon. Tentacularity is symchthonic, wound with abyssal and dreadful graspings, frayings, and weavings, passing relays again and again, in the generative recursions that make up living and dying.

After I used the term *sympoiesis* in a grasp for something other than the lures of autopoiesis, Katie King told me about M. Beth Dempster's Master of Environmental Studies thesis written in 1998, in which she suggested the term *sympoiesis* for "collectively-producing systems that do not have self-defined spatial or temporal boundaries. Information and control are distributed among components. The systems are evolutionary and have the potential for surprising change." By contrast, autopoietic systems are "self-producing" autonomous units "with self defined spatial or temporal boundaries that tend to be centrally controlled, homeostatic, and predictable."[13] Dempster argued that many systems are mistaken for autopoietic that are really sympoietic. I think this point is important for thinking about rehabilitation (making livable again) and sustainability amid the porous tissues and open edges of damaged but still ongoing living worlds, like the planet earth and its denizens in current times being called the Anthropocene. If it is true that neither biology nor philosophy any longer supports the notion of independent organisms in environments, that is, interacting units plus contexts/rules, then sympoiesis is the name of the game in spades. Bounded (or neoliberal) individualism amended by autopoiesis is not good enough figurally or scientifically; it misleads us down deadly paths.

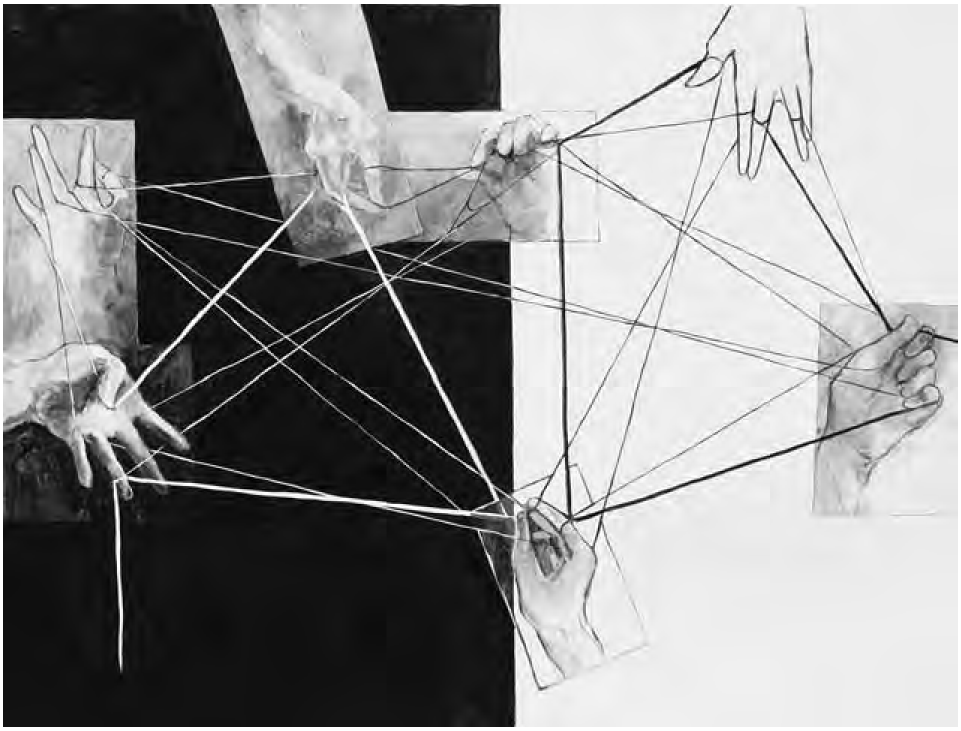
Barad's agential realism and intra-action become common sense, and perhaps a lifeline for Terran wayfarers.

SF, string figuring, is sympoietic. Thinking-with my work on cat's cradle, as well as with the work of another of her companions in thinking, Félix Guattari, Isabelle Stengers relayed back to me how players pass back and forth to each other the patterns-at-stake, sometimes conserving, sometimes proposing and inventing.

> More precisely, com-menting, if it means thinking-with, that is becoming-with, is in itself a way of relaying . . . But knowing that what you take has been held out entails a particular thinking "between." It does not demand fidelity, still less fealty, rather a particular kind of loyalty, the answer to the trust of the held out hand. Even if this trust is not in "you" but in "creative uncertainty," even if the consequences and meaning of what has been done, thought or written, do not belong to you anymore than they belonged to the one you take the relay from, one way or another the relay is now in your hands, together with the demand that you do not proceed with "mechanical confidence." [In cat's cradling, at least] two pairs of hands are needed, and in each successive step, one is "passive," offering the result of its previous operation, a string entanglement, for the other to operate, only to become active again at the next step, when the other presents the new entanglement. But it can also be said that each time the "passive" pair is the one that holds, and is held by the entanglement, only to "let it go" when the other one takes the relay.[14]

In passion and action, detachment and attachment, this is what I call cultivating response-ability; that is also collective knowing and doing, an ecology of practices. Whether we asked for it or not, the pattern is in our hands. The answer to the trust of the held-out hand: think we must.

Marilyn Strathern is an ethnographer of thinking practices. She defines anthropology as studying relations with relations—a hugely consequential, mind- and body-altering sort of commitment.[15] Nourished by her lifelong work in highland Papua New Guinea (Mt. Hagen), Strathern writes about accepting the risk of relentless contingency, of putting relations at risk with other relations, from unexpected worlds. Embodying the practice of feminist speculative fabulation in the scholarly mode, Strathern taught me—taught us—a simple but game-changing thing: "It matters what ideas we use to think other ideas."[16] I compost my soul in this hot pile. The worms are not human; their undulating bodies in-



2.2. *Cat's Cradle/String Theory*, Baila Goldenthal, 2008. Oil on canvas, 36 × 48 in. Courtesy of Maurya Simon and Tamara Ambroson.

gest and reach, and their feces fertilize worlds. Their tentacles make string figures.

It matters what thoughts think thoughts. It matters what knowledges know knowledges. It matters what relations relate relations. It matters what worlds world worlds. It matters what stories tell stories. Paintings by Baila Goldenthal are eloquent testimony to this mattering.[17]

What is it to surrender the capacity to think? These times called the Anthropocene are times of multispecies, including human, urgency: of great mass death and extinction; of onrushing disasters, whose unpredictable specificities are foolishly taken as unknowability itself; of refusing to know and to cultivate the capacity of response-ability; of refusing to be present in and to onrushing catastrophe in time; of unprecedented looking away. Surely, to say "unprecedented" in view of the realities of the last centuries is to say something almost unimaginable. How can we think in times of urgencies *without* the self-indulgent and self-fulfilling myths of apocalypse, when every fiber of our being is interlaced, even complicit, in the webs of processes that must somehow be engaged and repatterned? Recursively, whether we asked for it or not, the pattern is in our hands. The answer to the trust of the held-out hand: think we must.

Instructed by Valerie Hartouni, I turn to Hannah Arendt's analysis of the Nazi war criminal Adolf Eichmann's inability to think. In that surrender of thinking lay the "banality of evil" of the particular sort that could make the disaster of the Anthropocene, with its ramped-up genocides and speciescides, come true.[18] This outcome is still at stake; think we must; we must think! In Hartouni's reading, Arendt insisted that thought was profoundly different from what we might call disciplinary knowledge or science rooted in evidence, or the sorting of truth and belief or fact and opinion or good and bad. Thinking, in Arendt's sense, is not a process for evaluating information and argument, for being right or wrong, for judging oneself or others to be in truth or error. All of that is important, but not what Arendt had to say about the evil of thoughtlessness that I want to bring into the question of the geohistorical conjuncture being called the Anthropocene.

Arendt witnessed in Eichmann not an incomprehensible monster, but something much more terrifying—she saw commonplace thoughtlessness. That is, here was a human being unable to make present to himself what was absent, what was not himself, what the world in its sheer not-one-selfness is and what claims-to-be inhere in not-oneself. Here was someone who could not be a wayfarer, could not entangle, could not track the lines of living and dying, could not cultivate response-ability, could not make present to itself what it is doing, could not live in consequences or with consequence, could not compost. Function mattered, duty mattered, but the world did not matter for Eichmann. The world does not matter in ordinary thoughtlessness. The hollowed-out spaces are all filled with assessing information, determining friends and enemies, and doing busy jobs; negativity, the hollowing out of such positivity, is missed, an astonishing abandonment of thinking.[19] This quality was not an emotional lack, a lack of compassion, although surely that was true of Eichmann, but a deeper surrender to what I would call immateriality, inconsequentiality, or, in Arendt's and also my idiom, thoughtlessness. Eichmann was astralized right out of the muddle of thinking into the practice of business as usual no matter what. There was no way the world could become for Eichmann and his heirs—us?—a "matter of care."[20] The result was active participation in genocide.

The anthropologist, feminist, cultural theorist, storyteller, and connoisseur of the tissues of heterogeneous capitalism, globalism, traveling worlds, and local places Anna Tsing examines the "arts of living on a damaged planet,"[21] or, in the subtitle of her book, "the possibility of life in Capitalist ruins." She performs thinking of a kind that must be cultivated in the all-too-ordinary urgencies of onrushing multispecies extinctions, genocides, immiserations, and exterminations. I name these things urgencies rather than emergencies because the latter word connotes something approaching apocalypse and its mythologies. Urgencies have other temporalities, and these times are ours. These are the times we must think; these are the times of urgencies that need stories.

Following matsutake mushrooms in their fulminating assemblages of Japanese, Americans, Chinese, Koreans, Hmong, Lao, Mexicans, fungal spores and mats, oak and pine trees, mycorrhizal symbioses, pickers, buyers, shippers, restaurateurs, diners, businessmen, scientists, foresters, DNA sequencers and their changing species, and much more, Tsing practices sympoietics in edgy times. Refusing either to look away or to reduce the earth's urgency to an abstract system of causative destruction, such as a Human Species Act or undifferentiated Capitalism, Tsing argues that precarity—failure of the lying promises of Modern Progress—characterizes the lives and deaths of all terran critters in these times. She looks for the eruptions of unexpected liveliness and the contaminated and nondeterministic, unfinished, ongoing practices of living in the ruins. She performs the force of stories; she shows in the flesh how it matters which stories tell stories as a practice of caring and thinking. "If a rush of troubled stories is the best way to tell contaminated diversity, then it's time to make that rush part of our knowledge practices . . . Matsutake's willingness to emerge in blasted landscapes allows us to explore the ruins that have become our collective home. To follow matsutake guides us to possibilities of coexistence within environmental disturbance. This is not an excuse for further human damage. Still, matsutake show one kind of collaborative survival."

Driven by radical curiosity, Tsing does the ethnography of "salvage accumulation" and "patchy capitalism," the kind that can no longer promise progress but can and does extend devastation and make precarity the name of our systematicity. There is no simple ethical, political, or theoretical point to take from Tsing's work; there is instead the force of engaging the world in the kind of thinking practices impossible for Eichmann's heirs. "Matsutake tell us about surviving collaboratively in disturbance and contamination. We need this skill for living in ruins."[22] This is not a longing for salvation or some other sort of optimistic politics; neither is it a cynical quietism in the face of the depth of the trouble. Rather, Tsing proposes a commitment to living and dying with response-ability in unexpected company. Such living and dying have the best chance of cultivating conditions for ongoingness.

The ecological philosopher and multispecies ethnographer Thom van Dooren also inhabits the layered complexities of living in times of extinction, extermination, and partial recuperation; he deepens our consideration of what thinking means, of what not becoming thoughtless exacts from all of us. In his extraordinary book *Flight Ways*, van Dooren accompanies situated bird species living on the extended edge of extinction, asking what it means to hold open space for another.[23] Such holding open is far from an innocent or obvious material or ethical practice; even when successful, it exacts tolls of suffering as well as surviving as individuals and as kinds. In his examination of the practices of the North American whooping crane species survival plan, for example, van Dooren details multiple kinds of hard multispecies captivities and labors, forced life, surrogate reproductive labor, and substitute dying—none of which should be forgotten, especially in successful projects. Holding open space might—or might not—delay extinction in ways that make possible composing or recomposing flourishing naturalcultural assemblages. *Flight Ways* shows how extinction is not a point, not a single event, but more like an extended edge or a widened ledge. Extinction is a protracted slow death that unravels great tissues of ways of going on in the world for many species, including historically situated people.[24]

Van Dooren proposes that mourning is intrinsic to cultivating response-ability. In his chapter on conservation efforts for Hawaiian crows (ʻAlalā for Hawaiians, *Corvus hawaiiensis* for Linneans), whose forest homes and foods as well as friends, chicks, and mates have largely disappeared, van Dooren argues that it is not just human people who mourn the loss of loved ones, of place, of lifeways; other beings mourn as well. Corvids grieve loss. The point rests on biobehavioral studies as well as intimate natural history; neither the capacity nor the practice of mourning is a human specialty. Outside the dubious privileges of human exceptionalism, thinking people must learn to grieve-with.

> Mourning is about dwelling with a loss and so coming to appreciate what it means, how the world has changed, and how we must *ourselves* change and renew our relationships if we are to move forward from here. In this context, genuine mourning should open us into an aware-

> ness of our dependence on and relationships with those countless others being driven over the edge of extinction . . . The reality, however, is that there *is* no avoiding the necessity of the difficult cultural work of reflection and mourning. This work is not opposed to practical action, rather it is the foundation of any sustainable and informed response.

Grief is a path to understanding entangled shared living and dying; human beings must grieve *with*, because we are in and of this fabric of undoing. Without sustained remembrance, we cannot learn to live with ghosts and so cannot think. Like the crows and with the crows, living and dead "we are at stake in each other's company."[25]

At least one more SF thread is crucial to the practice of thinking, which must be thinking-with: storytelling. It matters what thoughts think thoughts; it matters what stories tell stories. "Urban Penguins: Stories for Lost Places," van Dooren's chapter on Sydney Harbor's Little Penguins (*Eudyptula minor*), succeeds in crafting a nonanthropomorphic, nonanthropocentric sense of storied place. In their resolutely "philopatric" (home loving) nesting and other life practices, these urban penguins—real, particular birds—story place, *this* place, not just any place. Establishing the reality and vivid specificity of penguin-storied place is a major material-semiotic accomplishment. Storying cannot any longer be put into the box of human exceptionalism. Without deserting the terrain of behavioral ecology and natural history, this writing achieves powerful attunement to storying in penguin multimodal semiotics.[26]

Ursula Le Guin taught me the carrier bag theory of storytelling and of naturalcultural history. Her theories, her stories, are capacious bags for collecting, carrying, and telling the stuff of living. "A leaf a gourd a shell a net a bag a sling a sack a bottle a pot a box a container. A holder. A recipient."[27] So much of earth history has been told in the thrall of the fantasy of the first beautiful words and weapons, of the first beautiful weapons *as* words and vice versa. Tool, weapon, word: that is the word made flesh in the image of the sky god; that is the Anthropos. In a tragic story with only one real actor, one real world-maker, the hero, this is the Man-making tale of the hunter on a quest to kill and bring back the terrible bounty. This is the cutting, sharp, combative tale of action that defers the suffering of glutinous, earth-rotted passivity beyond bearing. All others in the prick tale are props, ground, plot space, or prey. They don't matter; their job is to be in the way, to be overcome, to be the road, the conduit, but not the traveler, not the begetter. The last thing the hero wants to know is that his beautiful words and weapons will be worthless without a bag, a container, a net.

Nonetheless, no adventurer should leave home without a sack. How did a sling, a pot, a bottle suddenly get in the story? How do such lowly things keep the story going? Or maybe even worse for the hero, how do those concave, hollowed-out things, those holes in Being, from the get-go generate richer, quirkier, fuller, unfitting, ongoing stories, stories with room for the hunter but which weren't and aren't about him, the self-making human, the human-making machine of history? The slight curve of the shell that holds just a little water, just a few seeds to give away and to receive, suggests stories of becoming-with, of reciprocal induction, of companion species whose job in living and dying is not to end the storying, the worlding. With a shell and a net, becoming human, becoming humus, becoming terran, has another shape—that is, the side-winding, snaky shape of becoming-with. To think-with is to stay with the naturalcultural multispecies trouble on earth. There are no guarantees, no arrow of time, no Law of History or Science or Nature in such struggles. There is only the relentlessly contingent SF worlding of living and dying, of becoming-with and unbecoming-with, of sympoiesis, and so, just possibly, of multispecies flourishing on earth.

Like Le Guin, Bruno Latour passionately understands the need to change the story, to learn somehow to narrate—to think—outside the prick tale of Humans in History, when the knowledge of how to murder each other—and along with each other, uncountable multitudes of the living earth—is not scarce. Think we must; we must think. That means, simply, we *must* change the story; the story *must* change. Le Guin writes, "Hence it is with a certain feeling of urgency that I seek the nature, subject, words of the other story, the untold one, the life story."[28] In this terrible time called the Anthropocene, Latour argues that the fundamentals of geopolitics have been blasted open. None of the parties in crisis can call on Providence, History, Science, Progress, or any other god trick outside the common fray to resolve the troubles.[29] A common livable world must be composed, bit by bit, or not at all. What used to be called nature has erupted into ordinary human affairs, and vice versa, in such a way and with such permanence as to change fundamentally means and prospects for going on, including going on at all. Searching for compositionist practices capable of building effective new collectives, Latour argues that we must learn to tell "Gaïa stories." If that word is too hard, then we can call our narrations "geostories," in which "all the former props and passive agents have become active without, for that, being part of a giant plot written by some overseeing entity."[30] Those who tell Gaia stories or geostories are the "Earthbound," those who eschew the dubious pleasures of transcendent plots of modernity and the purifying division of society and nature. Latour argues that we face a stark divide: "Some are readying themselves to live as Earthbound in the Anthropocene; others decided to remain as Humans in the Holocene."[31]

In much of his writing, Latour develops the language and imagery of trials of strength; and in thinking about the Anthropocene and the Earthbound, he extends that metaphor to develop the difference between a police action, where peace is restored by an already existing order, and war or politics, where real enemies must be overcome to establish what will be. Latour is determined to avoid the idols of a ready-to-hand fix, such as Laws of History, Modernity, the State, God, Progress, Reason, Decadence, Nature, Technology, or Science, as well as the debilitating disrespect for difference and shared finitude inherent in those who already know the answers toward those who only need to learn them—by force, faith, or self-certain pedagogy. Those who "believe" they have the answers to the present urgencies are terribly dangerous. Those who refuse to be *for* some ways of living and dying and not others are equally dangerous. Matters of fact, matters of concern,[32] and matters of care are knotted in string figures, in SF.

Latour embraces sciences, not Science. In geopolitics, "the important point here is to realize that the facts of the matter cannot be delegated to a higher unified authority that would have done the choice *in our stead*. Controversies—no matter how spurious they might be—are no excuse to delay the *decision* about which side represents our world *better*."[33] Latour *aligns* himself with the reports of the Intergovernmental Panel on Climate Change (IPCC); he does not *believe* its assessments and reports; he *decides* what is strong and trustworthy and what is not. He casts his lot with some worlds and worldings and not others. One need not hear Latour's "decision" discourse with an individualist ear; he is a compositionist intent on understanding how a common world, how collectives, are built-with each other, where all the builders are not human beings. This is neither relativism nor rationalism; it is SF, which Latour would call both sciences and scientifiction and I would call both sciences and speculative fabulation—all of which are political sciences, in our aligned approaches.

"Alignment" is a rich metaphor for wayfarers, for the Earthbound, and does not as easily as "decision" carry the tones of modernist liberal choice discourse, at least in the United States. Further, the refusal of the modernist category of belief is also crucial to my effort to persuade us to take up the Chthulucene and its tentacular tasks.[34] Like Stengers and like myself, Latour is a thoroughgoing materialist committed to an ecology of practices, to the mundane articulating of assemblages through situated work and play in the muddle of messy living and dying. Actual players, articulating with varied allies of all ontological sorts (molecules, colleagues, and much more), must compose and sustain what is and will be. Alignment in tentacular worlding must be a seriously tangled affair!

Intent on the crucial refusal of self-certainty and preexisting god tricks, which I passionately share, Latour turns to a resource—relentless reliance on the material-semiotic trope of trials of strength—that, I think, makes it unnecessarily hard to tell his and our needed new story. He defines war as the absence of a referee so that trials of strength must determine the legitimate authority. Humans in History and the Earthbound in the Anthropocene are engaged in trials of strength where there is no Referee who/which can establish what is/was/will be. History versus Gaia stories are at stake. Those trials—the war of the Earthbound with the Humans—would not be conducted with rockets and bombs; they would be conducted with every other imaginable resource and with no god trick from above to decide life and death, truth and error. But still, we are in the story of the hero and the first beautiful words and weapons, not in the story of the carrier bag. Anything not decided in the presence of the Authority is war; Science (singular and capitalized) is the Authority; the Authority conducts police actions. In contrast, sciences (always rooted in practices) are war. Therefore, in Latour's passionate speculative fabulation, such war is our only hope for real politics. The past is as much the contested zone as the present or future.

Latour's thinking and stories need a specific kind of enemies. He draws on Carl Schmitt's "political theology," which is a theory of peace through war, with the enemy as *hostis*, with all its tones of host, hostage, guest, and worthy enemy. Only with such an enemy, Schmitt and Latour hold, is there respect and a chance to be less, not more, deadly in conflict. Those who operate within the categories of Authority and of belief are notoriously prone to exterminationist and genocidal combat (it's hard to deny that!). They are lost without a pre-established Referee. The *hostis* demands much better. But all the action remains within the narrative vise of trials of strength, of mortal combat, within which the knowledge of how to murder each other remains well entrenched. Latour makes clear that he does not *want* this story, but he does not propose another. The only real possibility for peace lies in the tale of the respected enemy, the *hostis*, and trials of strength. "But when you are at war, it is only through the throes of the encounters that the authority you have or don't have will be decided *depending whether you win or lose*."[35]

Schmitt's enemies do not allow the story to change in its marrow; the Earthbound need a more tentacular, less binary life story. Latour's Gaia stories deserve better companions in storytelling than Schmitt. The question of whom to think-with is immensely material. I do not think Latour's dilemma can be resolved in the terms of the Anthropocene. His Earthbound will have to trek into the Chthulucene to entangle with the ongoing, snaky, unheroic, tentacular, dreadful ones, the ones which/who craft material-semiotic netbags of little use in trials of strength but of great use in bringing home and sharing the means of living and dying well, perhaps even the means of ecological recuperation for human and more-than-human critters alike.

Shaping her thinking about the times called Anthropocene and "multi-faced Gaïa" (Stengers's term) in companionable friction with Latour, Isabelle Stengers does not ask that we recompose ourselves to become able, perhaps, to "face Gaïa." But like Latour and even more like Le Guin, one of her most generative SF writers, Stengers is adamant about changing the story. Focusing on intrusion rather than composition, Stengers calls Gaia a fearful and devastating power that intrudes on our categories of thought, that intrudes on thinking itself.[36] Earth/Gaia is maker and destroyer, not resource to be exploited or ward to be protected or nursing mother promising nourishment. Gaia is not a person but complex systemic phenomena that compose a living planet. Gaia's intrusion into our affairs is a radically materialist event that collects up multitudes. This intrusion threatens not life on earth itself—microbes will adapt, to put it mildly—but threatens the livability of earth for vast kinds, species, assemblages, and individuals in an "event" already under way called the Sixth Great Extinction.[37]

Stengers, like Latour, evokes the name of Gaia in the way James Lovelock and Lynn Margulis did, to name complex nonlinear couplings between processes that compose and sustain entwined but nonadditive subsystems as a partially cohering systemic whole.[38] In this hypothesis, Gaia is autopoietic—self-forming, boundary maintaining, contingent, dynamic, and stable under some conditions but not others. Gaia is not reducible to the sum of its parts, but achieves finite systemic coherence in the face of perturbations within parameters that are themselves responsive to dynamic systemic processes. Gaia does not and could not care about human or other biological beings' intentions or desires or needs, but Gaia puts into question our very existence, we who have provoked its brutal mutation that threatens both human and nonhuman livable presents and futures. Gaia is not about a list of questions waiting for rational policies;[39] Gaia is an intrusive event that undoes thinking as usual. "She is what specifically questions the tales and refrains of modern history. There is only one real mystery at stake, here: it is the answer we, meaning those who belong to this history, may be able to create as we face the consequences of what we have provoked."[40]

Anthropocene

So, what have we provoked? Writing in the midst of California's historic multiyear drought and the explosive fire season of 2015, I need the photograph of a fire set deliberately in June 2009 by Sustainable Resource Alberta near the Saskatchewan River Crossing on the Icefields Parkway in order to stem the spread of mountain pine beetles, to create a fire barrier to future fires, and to enhance biodiversity. The hope is that this fire acts as an ally for resurgence. The devastating spread of the pine beetle across the North American West is a major chapter of climate change in the Anthropocene. So too are the predicted megadroughts and the extreme and extended fire seasons. Fire in the North American West has a complicated multispecies history; fire is an essential element for ongoing, as well as an agent of double death, the killing of ongoingness. The material semiotics of fire in our times are at stake.

Thus it is past time to turn directly to the time-space-global thing called Anthropocene.[41] The term seems to have been coined in the early 1980s by University of Michigan ecologist Eugene Stoermer (d. 2012), an expert in freshwater diatoms. He introduced the term to refer to growing evidence for the transformative effects of human activities on the earth. The name Anthropocene made a dramatic star appearance in globalizing discourses in 2000 when the Dutch Nobel Prize–winning atmospheric chemist Paul Crutzen joined Stoermer to propose that human activities had been of such a kind and magnitude as to merit the use of a new geological term for a new epoch, superseding the Holocene,

2.3. Icon for the Anthropocene: Flaming Forests. From Rocky Mountain House, Alberta, Canada, June 2, 2009. Photograph by Cameron Strandberg.

which dated from the end of the last ice age, or the end of the Pleistocene, about twelve thousand years ago. Anthropogenic changes signaled by the mid-eighteenth-century steam engine and the planet-changing exploding use of coal were evident in the airs, waters, and rocks.[42] Evidence was mounting that the acidification and warming of the oceans are rapidly decomposing coral reef ecosystems, resulting in huge ghostly white skeletons of bleached and dead or dying coral. That a symbiotic system—coral, with its watery world-making associations of cnidarians and zooanthellae with many other critters too—indicated such a global transformation will come back into our story.

But for now, notice that the Anthropocene obtained purchase in popular and scientific discourse in the context of ubiquitous urgent efforts to find ways of talking about, theorizing, modeling, and managing a Big Thing called Globalization. Climate-change modeling is a powerful positive feedback loop provoking change-of-state in systems of political and ecological discourses.[43] That Paul Crutzen was both a Nobel laureate and an atmospheric chemist mattered. By 2008, many scientists around the world had adopted the not-yet-official but increasingly indispensable term;[44] and myriad research projects, performances, installations, and conferences in the arts, social sciences, and humanities found the term mandatory in their naming and thinking, not least for facing both accelerating extinctions across all biological taxa and also multispecies, including human, immiseration across the expanse of Terra. Fossil-burning human beings seem intent on making as many new fossils as possible as fast as possible. They will be read in the strata of the rocks on the land and under the waters by the geologists of the very near future, if not already. Perhaps, instead of the fiery forest, the icon for the Anthropocene should be Burning Man![45]

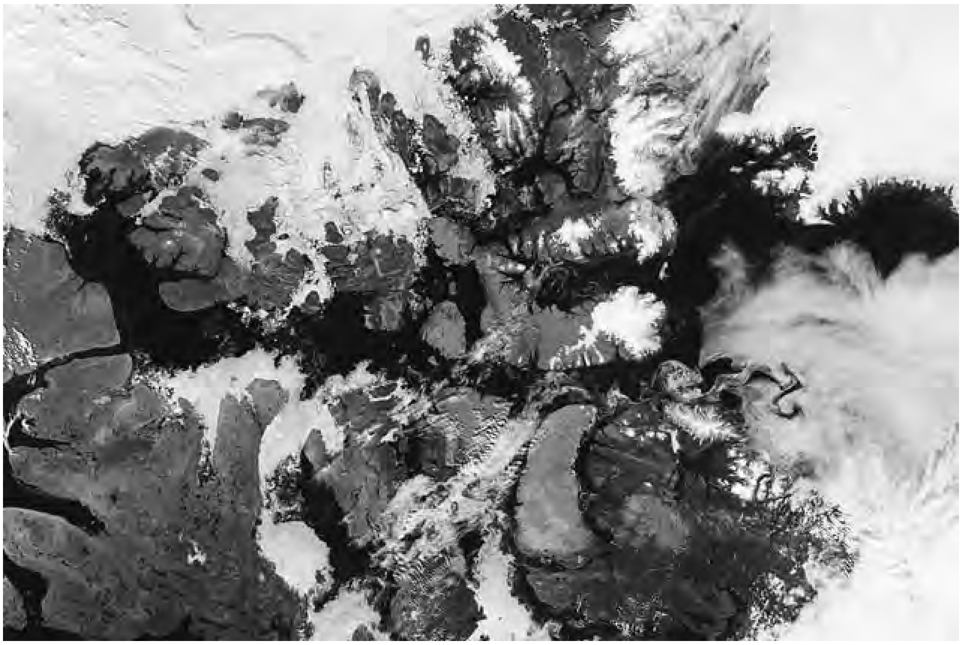
The scale of burning ambitions of fossil-making man—of this Anthropos whose hot projects for accelerating extinctions merits a name for a geological epoch—is hard to comprehend. Leaving aside all the other accelerating extractions of minerals, plant and animal flesh, human homelands, and so on, surely, we want to say, the pace of development of renewable energy technologies and of political and technical carbon pollution-abatement measures, in the face of palpable and costly ecosystem collapses and spreading political disorders, will mitigate, if not eliminate, the burden of planet-warming excess carbon from burning still more fossil fuels. Or, maybe the financial troubles of the global coal and oil industries by 2015 would stop the madness. Not so. Even casual acquaintance with the daily news erodes such hopes, but the trouble is worse than what even a close reader of IPCC documents and the press will find. In "The Third Carbon Age," Michael Klare, a professor of Peace and World Security Studies at Hampshire College, lays out strong evidence against the idea that the old age of coal, replaced by the recent age of oil, will be replaced by the age of renewables.[46] He details the large and growing global national and corporate investments in renewables; clearly, there are big profit and power advantages to be had in this sector. And at the same time, every imaginable, and many unimaginable, technologies and strategic measures are being pursued by all the big global players to extract every last calorie of fossil carbon, at whatever depth and in whatever formations of sand, mud, or rock, and with whatever horrors of travel to distribution and use points, to burn before someone else gets at that calorie and burns it first in the great prick story of the first and the last beautiful words and weapons.[47] In what he calls the Age of Unconventional Oil and Gas, hydro-fracking is the tip of the (melting) iceberg. Melting of the polar seas, terrible for polar bears and for coastal peoples, is very good for big competitive military, exploration, drilling, and tanker shipping across the northern passages. Who needs an icebreaker when you can count on melting ice?[48]

A complex systems engineer named Brad Werner addressed a session at the meetings of the American Geophysical Union in San Francisco in 2012. His point was quite simple: scientifically speaking, global capitalism "has made the depletion of resources so rapid, convenient and barrier-free that 'earth-human systems' are becoming dangerously unstable in response." Therefore, he argued, the only scientific thing to do is revolt! Movements, not just individuals, are critical. What is required is action and thinking that do not fit within the dominant capitalist culture; and, said Werner, this is a matter not of opinion, but of geophysical dynamics. The reporter who covered this session summed up Werner's address: "He is saying that his research shows that our entire economic paradigm is a threat to ecological stability."[49] Werner is not the first or the last researcher and maker of matters of concern to argue this point, but his clarity at a scientific meeting is bracing. Revolt! Think we must; we must think. Actually think, not like Eichmann the Thoughtless. Of course, the devil is in the details—how to revolt? How to matter and not just want to matter?

Capitalocene

But at least one thing is crystal clear. No matter how much he might be caught in the generic masculine universal and how much he only looks up, the Anthropos did not do this fracking thing and he should not name this double-death-loving epoch. The Anthropos is not Burning Man after all. But because the word is already well entrenched and seems less controversial to many important players compared to the Capitalocene, I know that we will continue to need the term *Anthropocene*. I will use it too, sparingly; what and whom the Anthropocene collects in its refurbished netbag might prove potent for living in the ruins and even for modest terran recuperation.

Still, if we could only have one word for these SF times, surely it must be the Capitalocene.[50] Species Man did not shape the conditions for the Third Carbon Age or the Nuclear Age. The story of Species Man as the agent of the Anthropocene is an almost laughable rerun of the great phallic humanizing and modernizing Adventure, where man, made in the image of a vanished god, takes on superpowers in his secular-sacred ascent, only to end in tragic detumescence, once again. Autopoietic, self-making man came down once again, this time in tragic system failure, turning biodiverse ecosystems into flipped-out deserts of slimy mats



2.4. Icon for the Capitalocene: Sea Ice Clearing from the Northwest Passage, Data 2012. NASA Visible Earth image by Jesse Allen, 2015, using data from the Land Atmosphere Near Real-Time Capability for EOS (LANCE). National Snow and Ice Data Center.

and stinging jellyfish. Neither did technological determinism produce the Third Carbon Age. Coal and the steam engine did not determine the story, and besides the dates are all wrong, not because one has to go back to the last ice age, but because one has to at least include the great market and commodity reworldings of the long sixteenth and seventeenth centuries of the current era, even if we think (wrongly) that we can remain Euro-centered in thinking about "globalizing" transformations shaping the Capitalocene.[51] One must surely tell of the networks of sugar, precious metals, plantations, indigenous genocides, and slavery, with their labor innovations and relocations and recompositions of critters and things sweeping up both human and nonhuman workers of all kinds. The infectious industrial revolution of England mattered hugely, but it is only one player in planet-transforming, historically situated, new enough, worlding relations. The relocation of peoples, plants, and animals; the leveling of vast forests; and the violent mining of metals preceded the steam engine; but that is not a warrant for wringing one's hands about the perfidy of the Anthropos, or of Species Man, or of Man the Hunter.

The systemic stories of the linked metabolisms, articulations, or coproductions (pick your metaphor) of economies and ecologies, of histories and human and nonhuman critters, must be relentlessly opportunistic and contingent. They must also be relentlessly relational, sympoietic, and consequential.[52] They are terran, not cosmic or blissed or cursed into outer space. The Capitalocene is terran; it does not have to be the last biodiverse geological epoch that includes our species too. There are so many good stories yet to tell, so many netbags yet to string, and not just by human beings.

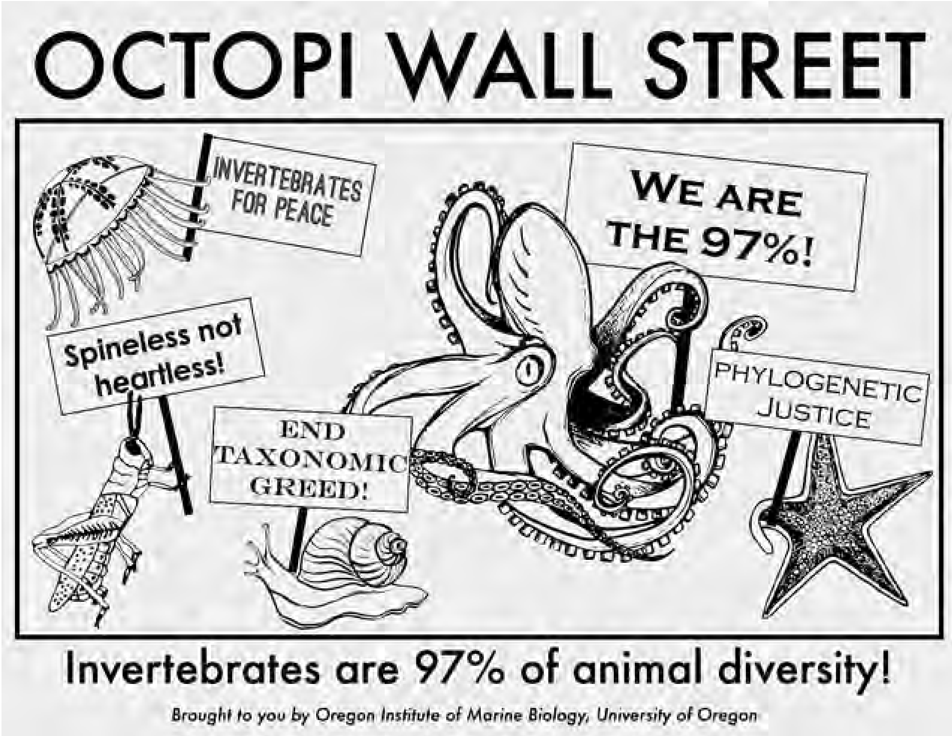
As a provocation, let me summarize my objections to the Anthropocene as a tool, story, or epoch to think with: (1) The myth system associated with the Anthropos is a setup, and the stories end badly. More to the point, they end in double death; they are not about ongoingness. It is hard to tell a good story with such a bad actor. Bad actors need a story, but not the whole story. (2) Species Man does not make history. (3) Man plus Tool does not make history. That is the story of History human exceptionalists tell. (4) That History must give way to geostories, to Gaia stories, to symchthonic stories; terrans do webbed, braided, and tentacular living and dying in sympoietic multispecies string figures; they do not do History. (5) The human social apparatus of the Anthropocene tends to be top-heavy and bureaucracy prone. Revolt needs other forms of action and other stories for solace, inspiration, and effectiveness. (6) Despite its reliance on agile computer modeling and autopoietic systems theories, the Anthropocene relies too much on what should be an "unthinkable" theory of relations, namely the old one of bounded utilitarian individualism—preexisting units in competition relations that take up all the air in the atmosphere (except, apparently, carbon dioxide). (7) The sciences of the Anthropocene are too much contained within restrictive systems theories and within evolutionary theories called the Modern Synthesis, which for all their extraordinary importance have proven unable to think well about sympoiesis, symbiosis, symbiogenesis, development, webbed ecologies, and microbes. That's a lot of trouble for adequate evolutionary theory. (8) Anthropocene is a term most easily meaningful and usable by intellectuals in wealthy classes and regions; it is not an idiomatic term for climate, weather, land, care of country, or much else in great swathes of the world, especially but not only among indigenous peoples.

I am aligned with feminist environmentalist Eileen Crist when she writes against the managerial, technocratic, market-and-profit besotted, modernizing, and human-exceptionalist business-as-usual commitments of so much Anthropocene discourse. This discourse is not simply wrong-headed and wrong-hearted in itself; it also saps our capacity for imagining and caring for other worlds, both those that exist precariously now (including those called wilderness, for all the contaminated history of that term in racist settler colonialism) and those we need to bring into being in alliance with other critters, for still possible recuperating pasts, presents, and futures. "Scarcity's deepening persistence, and the suffering it is auguring for all life, is an artifact of human exceptionalism at every level." Instead, a humanity with more earthly integrity "invites the *priority* of our pulling back and scaling down, of welcoming limitations of our numbers, economies, and habitats for the sake of a higher, more inclusive freedom and quality of life."[53]

If Humans live in History and the Earthbound take up their task within the Anthropocene, too many Posthumans (and posthumanists, another gathering altogether) seem to have emigrated to the Anthropocene for my taste. Perhaps my human and nonhuman people are the dreadful Chthonic ones who snake within the tissues of Terrapolis.

Note that insofar as the Capitalocene is told in the idiom of fundamentalist Marxism, with all its trappings of Modernity, Progress, and History, that term is subject to the same or fiercer criticisms. The stories of both the Anthropocene and the Capitalocene teeter constantly on the brink of becoming much Too Big. Marx did better than that, as did Darwin. We can inherit their bravery and capacity to tell big-enough stories without determinism, teleology, and plan.[54]

Historically situated relational worldings make a mockery both of the binary division of nature and society and of our enslavement to Progress and its evil twin, Modernization. The Capitalocene was relationally made, and not by a secular godlike anthropos, a law of history, the machine itself, or a demon called Modernity. The Capitalocene must be relationally unmade in order to compose in material-semiotic SF patterns and stories something more livable, something Ursula K. Le Guin could be proud of. Shocked anew by our—billions of earth habitants', including your and my—ongoing daily assent in practice to this thing called capitalism, Philippe Pignarre and Isabelle Stengers note that denunciation has been singularly ineffective, or capitalism would have long ago vanished from the earth. A dark bewitched commitment to the lure of Progress (and its polar opposite) lashes us to endless infernal alternatives, as if we had no other ways to reworld, reimagine, relive, and



2.5. *Octopi Wall Street*: Symchthonic revolt. Art by Marley Jarvis, Laurel Hiebert, Kira Treibergs, 2011. Oregon Institute of Marine Biology.

reconnect with each other, in multispecies well-being. This explication does not excuse us from doing many important things better; quite the opposite. Pignarre and Stengers affirm on-the-ground collectives capable of inventing new practices of imagination, resistance, revolt, repair, and mourning, and of living and dying well. They remind us that the established disorder is not necessary; another world is not only urgently needed, it is possible, but not if we are ensorcelled in despair, cynicism, or optimism, and the belief/disbelief discourse of Progress.[55] Many Marxist critical and cultural theorists, at their best, would agree.[56] So would the tentacular ones.[57]

Chthulucene

Reaching back to generative complex systems approaches by Lovelock and Margulis, Gaia figures the Anthropocene for many contemporary Western thinkers. But an unfurling Gaia is better situated in the Chthulucene, an ongoing temporality that resists figuration and dating and demands myriad names. Arising from Chaos,[58] Gaia was and is a powerful intrusive force, in no one's pocket, no one's hope for salvation, capable of provoking the late twentieth century's best autopoietic complex systems thinking that led to recognizing the devastation caused by anthropogenic processes of the last few centuries, a necessary counter to the Euclidean figures and stories of Man.[59] Brazilian anthropologists and philosophers Eduardo Viveiros de Castro and Déborah Danowski exorcise lingering notions that Gaia is confined to the ancient Greeks and subsequent Eurocultures in their refiguring the urgencies of our times in the post-Eurocentric conference "The Thousand Names of Gaia."[60] Names, not faces, not morphs of the same, something else, a thousand somethings else, still telling of linked ongoing generative and destructive worlding and reworlding in this age of the earth. We need another figure, a thousand names of something else, to erupt out of the Anthropocene into another, big-enough story. Bitten in a California redwood forest by spidery *Pimoa chthulhu*, I want to propose snaky Medusa and the many unfinished worldings of her antecedents, affiliates, and descendants. Perhaps Medusa, the only mortal Gorgon, can bring us into the holobiomes of Terrapolis and heighten our chances for dashing the twenty-first-century ships of the Heroes on a living coral reef instead of allowing them to suck the last drop of fossil flesh out of dead rock.

The terra-cotta figure of Potnia Theron, the Mistress of the Animals, depicts a winged goddess wearing a split skirt and touching a bird with each hand.[61] She is a vivid reminder of the breadth, width, and temporal reach into pasts and futures of chthonic powers in Mediterranean and Near Eastern worlds and beyond.[62] Potnia Theron is rooted in Minoan and then Mycenean cultures and infuses Greek stories of the Gorgons (especially the only mortal Gorgon, Medusa) and of Artemis. A kind of far-traveling Ur-Medusa, the Lady of the Beasts is a potent link between Crete and India. The winged figure is also called Potnia Melissa, Mistress of the Bees, draped with all their buzzing-stinging-honeyed gifts. Note the acoustic, tactile, and gustatory senses elicited by the Mistress and her sympoietic, more-than-human flesh. The snakes and bees are more like stinging tentacular feelers than like binocular eyes, although these critters see too, in compound-eyed insectile and many-armed optics.

In many incarnations around the world, the winged bee goddesses are very old, and they are much needed now.[63] Potnia Theron/Melissa's snaky locks and Gorgon face tangle her with a diverse kinship of chthonic earthly forces that travel richly in space and time. The Greek word Gorgon translates as dreadful, but perhaps that is an astralized, patriarchal hear-

2.6. Icon for the Chthulucene. Potnia Theron with a Gorgon Face. Type of Potnia Theron, Kameiros, Rhodes, circa 600 BCE, terracotta, 13 in. diameter, British Museum, excavated by Auguste Salzmann and Sir Alfred Bilotti; purchased 1860. Photograph by Marie-Lan Nguyen, © 2007.

ing of much more awe-ful stories and enactments of generation, destruction, and tenacious, ongoing terran finitude. Potnia Theron/Melissa/Medusa give faciality a profound makeover, and that is a blow to modern humanist (including technohumanist) figurations of the forward-looking, sky-gazing Anthropos. Recall that the Greek *chthonios* means "of, in, or under the earth and the seas"—a rich terran muddle for SF, science fact, science fiction, speculative feminism, and speculative fabulation. The chthonic ones are precisely not sky gods, not a foundation for the Olympiad, not friends to the Anthropocene or Capitalocene, and definitely not finished. The Earthbound can take heart—as well as action.

The Gorgons are powerful winged chthonic entities without a proper genealogy; their reach is lateral and tentacular; they have no settled lineage and no reliable kind (genre, gender), although they are figured and storied as female. In old versions, the Gorgons twine with the Erinyes (Furies), chthonic underworld powers who avenge crimes against the natural order. In the winged domains, the bird-bodied Harpies carry out these vital functions.[64] Now, look again at the birds of Potnia Theron and ask what they do. Are the Harpies their cousins? Around 700 BCE Hesiod imagined the Gorgons as sea demons and gave them sea deities for parents. I read Hesiod's *Theogony* as laboring to stabilize a very bumptious queer family. The Gorgons erupt more than emerge; they are intrusive in a sense akin to what Stengers understands by Gaia.

The Gorgons turned men who looked into their living, venomous, snake-encrusted faces into stone. I wonder what might have happened if those men had known how to politely greet the dreadful chthonic ones. I wonder if such manners can still be learned, if there is time to learn now, or if the stratigraphy of the rocks will only register the ends and end of a stony Anthropos.[65]

Because the deities of the Olympiad identified her as a particularly dangerous enemy to the sky gods' succession and authority, mortal Medusa is especially interesting for my efforts to propose the Chthulucene as one of the big-enough stories in the netbag for staying with the trouble of our ongoing epoch. I resignify and twist the stories, but no more than the Greeks themselves constantly did.[66] The hero Perseus was dispatched to kill Medusa; and with the help of Athena, head-born favorite daughter of Zeus, he cut off the Gorgon's head and gave it to his accomplice, this virgin goddess of wisdom and war. Putting Medusa's severed head face-forward on her shield, the Aegis, Athena, as usual, played traitor to the Earthbound; we expect no better from motherless mind children. But great good came of this murder-for-hire, for from Medusa's dead body came the winged horse Pegasus. Feminists have a special friendship with horses. Who says these stories do not still move us materially?[67] And from the blood dripping from Medusa's severed head came the rocky corals of the western seas, remembered today in the taxonomic names of the Gorgonians, the coral-like sea fans and sea whips, composed in symbioses of tentacular animal cnidarians and photosynthetic algal-like beings called zooanthellae.[68]

With the corals, we turn definitively away from heady facial representations, no matter how snaky. Even Potnia Theron, Potnia Melissa, and Medusa cannot alone spin out the needed tentacularities. In the tasks of thinking, figuring, and storytelling, the spider of my first pages, *Pimoa chthulhu*, allies with the decidedly nonvertebrate critters of the seas. Corals align with octopuses, squids, and cuttlefish. Octopuses are called spiders of the seas, not only for their tentacularity, but also for their predatory habits. The tentacular chthonic ones have to eat; they are at table, *cum panis*, companion species of terra. They are good figures for the luring, beckoning, gorgeous, finite, dangerous precarities of the Chthulucene. This Chthulucene is neither sacred nor secular; this earthly worlding is thoroughly terran, muddled, and mortal—and at stake now.

Mobile, many-armed predators, pulsating through and over the coral reefs, octopuses are called spiders of the sea. And so *Pimoa chthulhu* and *Octopus cyanea* meet in the webbed tales of the Chthulucene.[69]

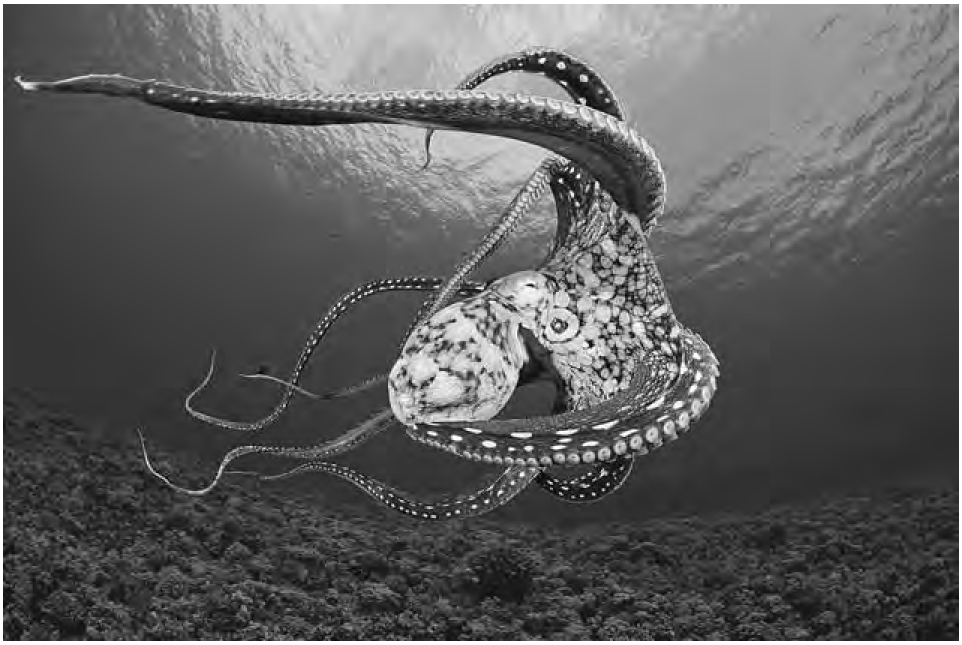
All of these stories are a lure to proposing the Chthulucene as a needed third story, a third netbag for collecting up what is crucial for ongoing, for staying with the trouble.[70] The chthonic ones are not confined to a vanished past. They are a buzzing, stinging, sucking swarm now, and human beings are not in a separate compost pile. We are humus, not Homo, not anthropos; we are compost, not posthuman. As a suffix, the word *kainos*, "-cene," signals new, recently made, fresh epochs of the thick present. To renew the biodiverse powers of terra is the sympoietic work and play of the Chthulucene. Specifically, unlike either the Anthropocene or the Capitalocene, the Chthulucene is made up of ongoing multispecies stories and practices of becoming-with in times that remain at stake, in precarious times, in which the world is not finished and the sky has not fallen—yet. We are at stake to each other. Unlike the dominant dramas of Anthropocene and Capitalocene discourse, human beings are not the only important actors in the Chthulucene, with all other beings able simply to react. The order is reknitted: human beings are with and of the earth, and the biotic and abiotic powers of this earth are the main story.

However, the doings of situated, actual human beings matter. It matters with which ways of living and dying we cast our lot rather than others. It matters not just to human beings, but also to those many critters across taxa which and whom we have subjected to exterminations, extinctions, genocides, and prospects of futurelessness. Like it or not, we are in the string figure game of caring for and with precarious worldings made terribly more precarious by fossil-burning man making new fossils as rapidly as possible in orgies of the Anthropocene and Capitalocene. Diverse human and nonhuman players are necessary in every fiber of the tissues of the urgently needed Chthulucene story. The chief actors are not restricted to the too-big players in the too-big stories of Capitalism and the Anthropos, both of which invite odd apocalyptic panics and even odder disengaged denunciations rather than attentive practices of thought, love, rage, and care.

Both the Anthropocene and the Capitalocene lend themselves too readily to cynicism, defeatism, and self-certain and self-fulfilling predictions, like the "game over, too late" discourse I hear all around me these days, in both expert and popular discourses, in which both technotheocratic geoengineering fixes and wallowing in despair seem to coinfect any possible common imagination. Encountering the sheer not-us, more-than-human worlding of the coral reefs, with their requirements for ongoing living and dying of their myriad critters, is also to encounter the knowledge that at least 250 million human beings today depend directly on the ongoing integrity of these holobiomes for their own ongoing living and dying well. Diverse corals and diverse people and peoples are at stake to and with each other. Flourishing will be cultivated as a multispecies response-ability without the arrogance of the sky gods and their minions, or else biodiverse terra will flip out into something very slimy, like any overstressed complex adaptive system at the end of its abilities to absorb insult after insult.

Corals helped bring the Earthbound into consciousness of the Anthropocene in the first place. From the start, uses of the term *Anthropocene* emphasized human-induced warming and acidification of the oceans from fossil-fuel-generated CO_2 emissions. Warming and acidification are known stressors that sicken and bleach coral reefs, killing the photosynthesizing zooanthellae and so ultimately their cnidarian symbionts and all of the other critters belonging to myriad taxa whose worlding depends on intact reef systems. Corals of the seas and lichens of the land also bring us into consciousness of the Capitalocene, in which deep-sea mining and drilling in oceans and fracking and pipeline construction across delicate lichen-covered northern landscapes are fundamental to accelerating nationalist, transnationalist, and corporate unworlding.

But coral and lichen symbionts also bring us richly into the storied tissues of the thickly present Chthulucene, where it remains possible—just barely—to play a much better SF game, in nonarrogant collaboration with all those in the muddle. We are all lichens; so we can be scraped off the rocks by the Furies, who still erupt to avenge crimes against the earth. Alternatively, we can join in the metabolic transformations between and among rocks and critters for living and dying well. "'Do you realize,' the phytolinguist will say to the aesthetic critic, 'that [once upon a time] they couldn't even read Eggplant?' And they will smile at our



2.7. Day octopus, *Octopus cyanea*, in the water near Lanai, Hawaii. Photograph by David Fleethham. © OceanwideImages.com.

ignorance, as they pick up their rucksacks and hike on up to read the newly deciphered lyrics of the lichen on the north face of Pike's Peak.'"[71]

Attending to these ongoing matters returns me to the question that began this chapter. What happens when human exceptionalism and the utilitarian individualism of classical political economics become unthinkable in the best sciences across the disciplines and interdisciplines? Seriously unthinkable: not available to think with. Why is it that the epochal name of the Anthropos imposed itself at just the time when understandings and knowledge practices about and within symbiogenesis and sympoietics are wildly and wonderfully available and generative in all the humusities, including noncolonizing arts, sciences, and politics? What if the doleful doings of the Anthropocene and the unworldings of the Capitalocene are the last gasps of the sky gods, not guarantors of the finished future, game over? It matters which thoughts think thoughts. We must think!

The unfinished Chthulucene must collect up the trash of the Anthropocene, the exterminism of the Capitalocene, and chipping and shredding and layering like a mad gardener, make a much hotter compost pile for still possible pasts, presents, and futures.

Chapter Nine

The Mycocultural Revolution

Comprehend nature, then copy nature. – Viktor Schauberger

Ours is the era of unprecedented change. With major clashes between human activities and the environment becoming increasingly difficult to ignore, a great impetus to create more efficient and ecologically sound living models now confronts the world. In this problem lies a solution that is both exciting for its unlimited potential and challenging for its unknown fate. Beyond peak phosphorus, humanity faces a state of "peak everything" in which severe fuel and water shortages may only be a few short decades away. Global population is predicted to reach 9.2 billion in 2050, a number that cannot be met with current, scarcity-based food and medical systems. And as soil and air temperatures rapidly change and shift natural cycles, fungi are impacted, with the fruiting seasons of some mushrooms now extending to more than double their length compared to averages from the 1950s.[1] Such changes may result in increased decomposition rates, changes in successional patterns, and alterations in fungal symbioses, significant ecological impacts with unknown consequences.

In response to these pressures, environmental and social justice advocates demand the restructuring of governments and the replacement of extractive economic systems with models that accurately account for the cultural and ecological costs of human actions. At the same time, the potential depth of an individual's impact is constantly being reduced through the solution-oriented refinement of alternative food, housing, and social systems that not only reduce inputs and impacts, but also increase vitality in the culture at large. To these grassroots approaches, fungi are proving critical. As the loop-closers and system builders of Nature, fungi expand limits to growth while also providing numerous means for increasing nourishment, self-empowerment, and dignity throughout the design of any resilient living system.

Whereas 80-90% of agriculture's total biomass is currently discarded due to disease or inedibility, mushroom cultivation can convert these "wastes" into food, medicine, and functional items. Incorporated into agropastoral, perennial polycultures, soil fungi significantly increase the yield and integrity of such unified food systems. Through their support of plant growth, mycorrhizal fungi increase the establishment of sensitive and ecologically important flora like native bunch grasses and traditional forage crops, leading to reduced rates of desertification and increased soil stabilization and salinity tolerance. And when integrated into habitat corridors, fungi act as fodder to wildlife, helping reduce or reverse extirpation of important top-down and bottom-up trophic regulators.

By increasing the structural, compositional, and functional diversity of a home or habitat, the efficient, low-input needs of fungi provide novel functions for living systems that seek holistic means to bounce back from disruption, suppression, or shortage. From the elements of natural mushroom farming come processes and integrated living (eco)systems that reflect the connections of a mycelial network. Through this work, the mushroom farmer begins to mimic fungi in their lives and interactions. In effect, a regenerative culture is grown that can readily synergize, magnify, and celebrate numerous efforts and design systems that increase quality of life. Tending to fungi throughout the seasons, the mycelium becomes the map toward a better future. From nomadic, to horticultural, to agricultural societies, the next revolution in human life will undoubtedly be the rise of the mycoculture.

The 15 Principles of Natural Mushroom Farming and Regenerative Mycology

To begin cultivating fungi outdoors, their ecological habits must be integrated into the principles discussed in Chapter 8. Though outdoor work does not provide for the consistency that indoor cultivation offers, by allowing fungi to engage with the natural environment on their own terms one can engage in the art of ecological co-creation that acknowledges the various relationships and patterns fungi form in the world.

The following 15 design concepts are offered to help influence this work. Largely influenced by the ecologically inspired design system known as *permaculture*, these are not specific protocols, but guiding principles for integrating Nature's patterns into any installation's design. Like mycelium, permaculture designs integrate the features of an environment into a cohesive, efficient, and self-supporting system. By mycomimicking this concept in all aspects of a cultivation project's design, mushroom growers and homesteaders can learn to create personal pathways toward a regenerative future that is supportive of the webs that underlie our lives, our communities, and the ecologies we live within.

Observe and Work With Fungi

This concept applies to all cultivation work but it is especially important to recognize in outdoor installations where control of the environment is beyond the means of the cultivator. Through observation, one can learn to anticipate the success of future installations as the responses of the fungi to their environment become increasingly familiar. When fungi are encountered in the wild, take note of their substrate and the local ecology. Spend time in their home to understand how to recreate it. *This principle is reflected by the fungi in their surveying and responding to environments in ways that reflect the needs or limits of that habitat.*

Catch and Store Energy

The gifts of potential and kinetic energy offered by the Earth and Sun should be honored and collected wherever possible to increase the sustainability and independence of a natural mushroom farming system. Infrastructure and landscaping methods that efficiently collect solar energy, radiant heat, and water should be applied to reduce one's impact on the environment while simultaneously cultivating resilient mycoscapes. *This conservation of energy principle is reflected in the means by which fungi gather and store nutrients in their mycelium and later release them to efficiently navigate and steward their environment.*

Obtain a Flush

Harvesting a large flush of fungi not only brings joy and bounty to the table, it also encourages the cultivator and their students to pursue future cultivation projects. When mushroom installations fail due to poor design or management, it is easy for the beginner to get discouraged and abandon the practice. Tangible yields serve as a visual affirmation of the importance and value of natural mushroom farming and self-sufficiency in general, and help ensure the evolution and spawning of future cultivators. *This principle is exemplified by the fungi through their tireless efforts to always produce and distribute spores, regardless of environmental constraints.*

Apply Self-Regulation and Accept Feedback

Do not assume that you know how a fungus will respond to a novel condition. Experimentation is encouraged with mushroom cultivation, but it is best to maintain a sense of humility as you learn from the successes and failures of innovation. Use these lessons and insights to refine your next experiment. Don't get discouraged, get creative. *This principle is an integral aspect of fungal growth and development. Fungi epigenetically respond to changes in their environment in ways that are self-preserving, energy efficient, and regenerative for the whole ecosystem.*

Use and Value Renewable Resources

Mushroom cultivation is founded on the realization that agricultural "waste" streams can be transformed into high quality food and medicines. Similarly, many other elements and practices used in mushroom cultivation offer a range of outputs that can be creatively utilized. The most resilient mushroom farms utilize solar heat, fermentation, and biogas production when preparing substrates in place of fossil fuels and other non-renewable resources. Nearly every tool used in the cultivation process can be built from reusable materials, lowering costs and cultural debris. Substrates can be sequenced to host a range of species so as to maximize yields. And the fungi themselves can be valued for their variety of regenerative functions, not just for the taste of their fruit bodies. *The fungi reflect this principle in their efficient management and redistribution of resources within an environment.*

Up the Functions

Everything performs more than one function. The science of ecology is based in determining how the various "outputs" of an organism or element affect the environment as a whole. Well designed cultivation systems mimic natural systems by efficiently integrating the various outputs of the design's elements and taking advantage of every output an element has to offer. This concept is often referred to in permaculture as "stacking functions." At all times, consider how a given project or act can accomplish more goals in a shorter amount of time. In most systems currently designed by humans, fungal functions are entirely absent.

Permaculture design utilizes a number of tactics for increasing the efficiency of a living system. Many of these concepts are described in this chapter, in as much as they relate to fungal cultivation. However, these design concepts are only a foundation to build upon. As the field of appropriately applied mycology progresses, new integration strategies are bound to arise that will continue to raise the bar of understanding of what is possible when working with fungi. *This principle is embodied by the fungi in the range of actions that they efficiently engage with in their environment as a unified web of autonomous hyphae.*

Close Loops and Produce No Waste

There is no waste in Nature. To reduce the waste produced by mushroom cultivation, the byproducts of any operation should be utilized by another system on the farm. Contaminated or spent spawn can be employed in a number of ways, as noted in Chapter 8. Where possible, use glass or repurposed tools and containers in place of single-use plastic bags and agar plates. Non-renewable resources and substrates are best used for developing the infrastructure that leads to a self-reliant system. *This principle is witnessed in the fungi's capacity for recomposing the elements of plant and animal matter into the lush topsoil that breeds new life.*

Spawn from Patterns to Details

The various techniques of aseptic mushroom cultivation are based upon the principles and patterns of fungal biology and ecology. This concept readily expands to natural mushroom farming where an intimate understanding of the habits of fungi is needed to best enhance the success of any system. *This endless expansion of life is exemplified in the holographic growth of a mycelial network.*

Myceliate Rather Than Segregate

Everything is connected. The most resilient natural mushroom farming practices integrate fungi into multi-canopied food forests, annual vegetable production, and other installations intentionally inoculated with beneficial microbes. Creating such a diversity of organisms in a landscape not only enhances the overall productivity of a place, it can also stimulate the vigor of the fungus' mycelium and lead to a more robust installation. When the proper mixture of elements are applied to any cultivation system, their combined effect can often be greater than the sum of their individual outputs, enabling even small-scale installations to be highly productive. Recognizing the intimate connection that all life forms share with each other and their habitats imparts a reverence for the brilliance of Nature and the humility to support its longevity for present and future generations. *In natural systems, fungi thrive when they are enmeshed within a dynamic and harmonic ecosystem. Increasing diversity in an ecosystem is an inherent role that the fungi play as keystone species.*

Use Small, Slow, and Simple Solutions

Natural installations with fungi should be seen as long-term endeavors that gradually work to enhance landscapes over time, while occasionally producing crops. When learning to integrate fungi into more complex systems, start small to gain familiarity with your work and then scale up as your understanding increases. When designing installations that emphasize a regenerative or remediative function over fruit body yield, apply caution at first. Work in short bursts (pulses) and in small areas (patches) to observe the effects that your initial design has on the regenerative work that Nature is bringing in of its own accord. Where possible, make the smallest intervention in these cycles as possible.

Mushroom cultivation does not have to be difficult, overly elaborate, or expensive. Installations that follow the principles of natural cultivation and account for the specific needs of a given mushroom species are likely to succeed to some degree regardless of monetary or infrastructural constraints. Once established, well-designed mushroom operations can be self-reliant for years or decades. *This principle is seen in the slow, steady, and powerful march of microscopic hyphal threads as they ramify substrates and enhance ecologies over centuries.*

Use and Value a Diversity of Species and Strains

Each fungal species and strain offers its own unique blend of characteristics to an installation. Integrating a wide variety and number of fungal species, strains, and installations into your design increases the variety of functions offered by the fungi. This not only adds aesthetic and functional value to the land, it also increases the potential for the system to respond and adapt to future changes. Increased diversity and redundancy of species/strains increases one's mycological resilience. Supporting the growth of local fungal strains also helps to increase the geographic distribution and genetic diversity of these strains as their spores eventually spread from your installations along air currents. *The importance of diversity is found in the mixture of fungal and non-fungal species that abound in healthy ecosystems and in the incredible array of genetic expressions offered through the mating of Basidiomycete spores.*

Use a Diversity of Local Substrates and Increase Vitality

Sourcing local substrates reduces the environmental and economic impacts of importation. Developing strains that prefer a locally abundant waste stream or "weed" plant increases a system's resilience. Building soil by growing mushrooms on these substrates supports the cultivation of other crops that can feed animals and to produce substrates, which can in turn grow more mushrooms. *The fungi are regenerators of landscapes. They thrive under diversity and in return leave their habitat richer and more fertile than originally found.*

Expand the Edges and Value the Marginal

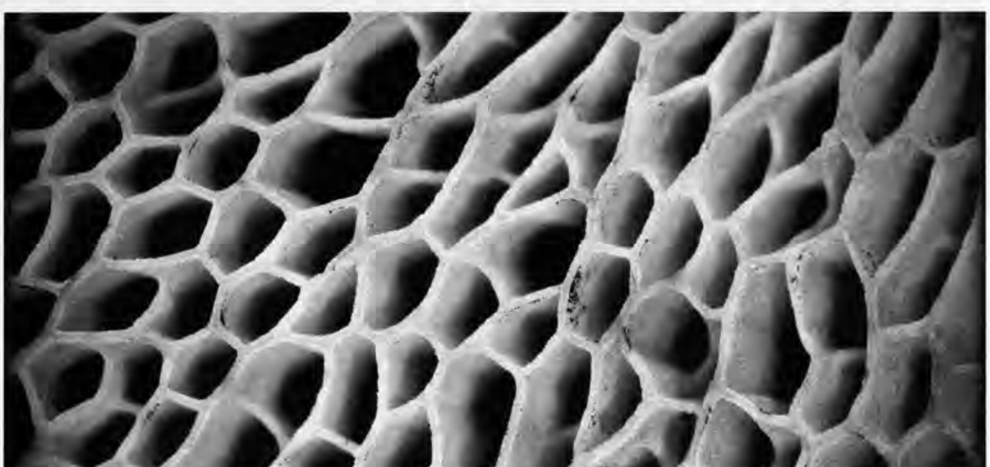
The boundary zone where two environments overlap, known as an *ecotone*, often supports a greater variety of species than the two individual environments on their own. When the total length of a zone's edge is increased through the creation of curves in preference to straight lines, the total available space for edge-dwelling species is thereby increased. Mushroom installations that follow contours and maintain a maximized edge length can support species diversity at a boundary. Marginalized and undervalued fungal species should be constantly reconsidered for any overlooked traits and the underutilized spaces of properties should likewise be evaluated for their ability to support a fungal installation. *The value of the edge in mycology is reflected in the rich diversity and density of fungal species that is often found where two habitats intersect. Mushrooms often fruit on the edges of an installation, where hyphal tips are most active, reflecting the importance of increasing edge length. Mycelium is only one cell thick, giving the network as a whole a very high surface area. Mycelium is almost entirely edge.*

Creatively Adapt to Change

Fungal installations are not static and need regular attention, modification, and/or relocation to maintain their health and vigor. Maintenance can include changing substrates, adding spawn, and improving designs. These modifications should be seen as stepping stones toward developing a familiarity and routine with natural cultivation that can anticipate and prepare for future shifts in the environment. Where appropriate, let Nature take its course in response to changes. This often provides unexpected alternatives to solving a problem. Design systems that are modular and easy to move or upgrade as new needs present themselves. The potential future shortages of fossil fuels and clean water (among many other resources) should serve as an impetus for all Radical Mycologists to design ever more regenerative systems that incorporate the undervalued gifts of fungi. *The fungi are one of the greatest model organisms for the strength and resilience that come from directly confronting and creatively responding to changes in the environment. They thrive under challenging environments and demonstrate the value of pursuing one's goals in the face of adversity.*

Spread Spores

The threads that weave together our contemporary knowledge of fungi have branched from the legacies of countless ancestors. To spawn the next generation of Radical Mycologists, our systems should actively seek to inspire and educate all those that encounter them. The abundance produced should be shared and acknowledged as a symbol of the numerous benefits that fungi provide. *The fungi, as with all the elements of Nature, present an endless array of lessons and insights for how to live in recognition of one's personal impact upon the lives of future generations.*



Natural farming is gentle and easy and indicates a return to the source of farming. A single step away from the source can only lead one astray.
– Masanobu Fukuoka[2]

The Polypore Mushrooms of the Genera *Ganoderma, Grifola* and *Polyporus*

The use of Polypores spans millennia and, of all the medicinal mushrooms, they reign supreme. Polypores are more often incorporated into the pharmacopeia of native peoples than any other type of mushroom. Historically, cultures from tropical Amazonia to the extreme northern sub-polar zones of Eurasia have discovered the power of Polypores in preserving and improving human health. Polypores have also figured prominently in the cosmological view of native peoples, often being referred to as sources of eternal strength and wisdom.

The Agaria of Sarmatia, a pre-Scythian culture, used a Polypore at the time of Christ to combat illness. They bestowed this Polypore with the name of *agarikon*, undoubtedly to honor its value to their society. The Greek philosopher Dioscorides, recorded its name as *agaricum* circa 200 A.D. Its use persisted throughout the Middle Ages and tea made from this wood conk was prescribed as one of the herbal remedies for tuberculosis.

Researchers believe this mushroom was *Fomitopsis officinalis,* a canker parasite of conifer trees. This same Polypore species has been retrieved from the graves of Pacific Northwest Coast Indian shamans. Thirteen individual carvings of this wood conk were collected in the late 1800's and mistakenly thought to be wood carvings until Blanchette et alia (1992) studied them. Used as a poultice to relieve swellings, inflammations, and sweating, this conk was called "the bread of ghosts", and thought to impart supernatural powers. In Haida mythology this or another Polypore (such as *Ganoderma applanatum*) is directly connected the origin and protection of the female spirit.

Figure 314. "Drawing of an argillite plate, carved by Charles Edenshaw in approximately 1890, depicting the Haida myth of the origin of women. Fungus Man is paddling the canoe with Raven in the bow in search of female genitalia. Of all the creatures that Raven placed in the stern of the canoe only Fungus Man had the supernatural powers to breach the spiritual barriers that protected the area where women's genital parts were located...." Redrawn from a photograph, courtesy of the Field Museum of Natural History, Chicago. (Blanchette et al.,1992, p. 122.)

Recently, in the winter of 1991, hikers in the Italian Alps came across the well preserved remains of man who died more than 5300 years ago. Dubbed the "Iceman" by the news media, he was well equipped with a knapsack, flint axe, and a string of dried Birch Polypores. (Birch Polypores, *Polyporus betulinus*, are now known as *Piptoporus betulinus*). These Polypores, like many others, can be used as tinder, for starting fires, and medicinally, in the treatment of wounds. Further, by boiling the mushrooms, a rich tea with anti-fatiguing, immunoenhancing, and soothing properties can be prepared. Of the essentials needed for travel into the wilderness, this intrepid adventurer had discovered the value of the noble Polypores. Ironically, as a group, the Polypores remain largely unexplored.

Throughout the past twenty years, I have been repeatedly told by travellers to Mexico, South America, and the Middle East of Christian churches who have for centuries paid homage to crosses in whose centers were glass spheres housing what appeared to be a species of wood conk. To this day, the identity of this revered conk remains shrouded in mystery. These are but a few examples. One naturally wonders how many species and uses have not yet come to the attention of Western science, perhaps forever obscured by the passage of time.

The most well known of the Polypores is, without question, Reishi or Ling Chi, known to mycologists as *Ganoderma lucidum.* So extensive are the medicinal claims for this fungus, this mushroom is also called the Panacea Polypore. Claimed to cure cancer, heart disease, diabetes, arthritis, high altitude sickness, sexual impotency, and even chronic fatigue syndrome, it is no wonder that this mushroom has been for centuries heralded as "The Mushroom of Immortality".

Two other Polypores enjoying reputations as medicinal fungi are Maitake, *Grifola frondosa*, and Zhu Ling, *Polyporus umbellatus*. Maitake has recently been found to be effective, *in vitro*, against the HIV virus by the National Cancer Institute of the National Institute of Health's anti-HIV drug screening program.* During a visit to the Institute of Materia Medica in Beijing, *Polyporus umbellatus* was reported to Stamets & Weil (1983) as being exceptionally effective against lung cancer. Aqueous extracts (tea) were given to patients directly after radiation therapy, with promising results.

The Polypores covered in this book are Reishi (*Ganoderma lucidum*), Maitake (*Grifola frondosa* (=*Polyporus frondosus*)), and Zhu Ling (*Polyporus umbellatus* = *Grifola umbellata*)). Many other Polypores, such as *Laetiporus sulphureus* (= *Polyporus sulphureus*), can be grown on stumps. Future editions of this book will expand on the number of Polypore species which I have successfully cultivated. A short list of these candidates includes, but is not limited to:

Albatrellus spp.
Daedalea quercina
Fomes fomentarius
Fomitopsis officinalis
Ganoderma applanatum (= Elfvingia applanata)
Ganoderma curtisii
Ganoderma oregonense
Ganoderma sinense
Ganoderma tsugae
Inonotus obliquus
Oligoporus spp.
Oxyporus nobilissimus and allies
Phellinus spp.
Piptoporus betulinus
Polyporus indigenus
Polyporus saporema
Trametes cinnabarinum (= ? Pycnoporus cinnabarinus)
Trametes (=Coriolus) versicolor & allies

Polypores are premier wood decomposers, and can produce annual or perennial fruitbodies. None

* De-replication and second tier screening studies are on-going at the time of this writing, as well as trials with AIDS-afflicted patients. The HIV virus *apparently* becomes encapsulated by a "carbohydrate condom" limiting reproduction. Hypothetically, I suspect two distinct modes of activity. First, the compounds in Maitake may stimulate the immune system by providing essential precursor-nutrients. Secondly, these compounds may also be a direct toxin to the virus. Until human studies can be funded, such hypotheses are purely speculative. However, if proven, this double-prong approach, combined with the fact that Maitake is an excellent edible and choice gourmet mushroom, brings Maitake to the forefront of the medicinal polypores. In my opinion, all polypores should be screened for their anti-cancer, anti-HIV and immuno-enhancing properties. There are probably more species with equal or greater potentials.

are known to be poisonous, although some people have allergic reactions to certain species. Some people taking MAO inhibitor anti-depressant medication can have allergic reactions to the edible polypores containing tyramine. Chicken of the Woods (*Laetiporus* (*Polyporus*) *sulphureus*) has been reported to contain alkaloids similar to those found in plants known to be psychoactive, like Kava Kava. (Lincoff & Mitchel (1977)).

The cultivation of these species can take several tracks. One track is to simply inoculate hardwood logs as with the cultivation of Shiitake. By burying the inoculated logs in sawdust or soil, moisture is better preserved, and fruitings extend over several years. Stumps can also be inoculated, although if other fungi have already captured that niche, production is inhibited. In outdoor environments, the first flushes of mushrooms are often delayed, not showing for several years after inoculation. However, since Polypores are naturally lower in moisture and require less water, outdoor patches require less maintenance than indoor methods.

By far the most dependable and rapid production system is the cultivation of Polypores indoors under controlled environmental conditions. Several techniques lead to success. One of the main differences between the cultivation of Polypores versus the fleshier, gilled mushrooms is that the Polypores do not enjoy, nor require, the heavy watering schedules and high humidities of the gilled mushrooms. Like most mushrooms, the Polypores are sensitive to carbon dioxide levels and light conditions. The development of the fruitbodies are extremely responsive to changes within the growing room environment. Many cultivators manipulate the environment to elicit substantial stem formation before cap development. Some Polypore species produce better fruitings if the substrate block is compressed after colonization. Other differences, unique to each species, are outlined in the forthcoming growth parameters.

Ganoderma lucidum (Wm. Curtis: Fries) Karsten

Introduction: A mushroom of many names, *Ganoderma lucidum* has been used medicinally by diverse peoples for centuries. The Japanese call this mushroom *Reishi* or *Mannentake* (10,000 Year Mushroom) whereas the Chinese & Koreans know it as *Ling Chi*, *Ling Chih*, or *Ling Zhi* (Mushroom (Herb) of Immortality). Renowned for its health stimulating properties, this mushroom is more often depicted in ancient Chinese, Korean, & Japanese art than any other. Ling Chi is traditionally associated with royalty, health & recuperation, longevity, sexual prowess, wisdom, and happiness. Ling Chi has been depicted in royal tapestries, often portrayed with renowned sages of the era. For a time, the Chinese even believed this mushroom could bring the dead to life when a tincture specifically made from it was laid upon one's chest.

The use of *Ganoderma lucidum* spans more than two millennia. The earliest mention of Ling Chi was in the era of the first emperor of China, Shih-huang of the Ch'in Dynasty (221-207 B.C.). Henceforth, depictions of this fungus proliferated through Chinese literature and art. In the time of the Han Dynasty (B.C. 206 - A.D. 220) while the imperial palace of Kan-ch'uan was being constructed, Ling Chi was found growing on timbers of the inner palace, producing nine "paired leaves". So striking was this good omen, that henceforth emissaries were sent far and wide in search of more collections of this unique fungus. Word of Ling Chi thus spread to Korea and Japan whereupon it was elevated to a status of near-reverence.

This mushroom is known by many in North America and Europe as one of the "Artist's Conk" fungi. (The true Artist Conk is *Ganoderma applanatum*.) As the fruitbody

Figure 315. A Tibetan Ling Chi "Tree" statuette made of wood, from pre-1600 AD. revered and protected in the Lama Temple, Beijing.

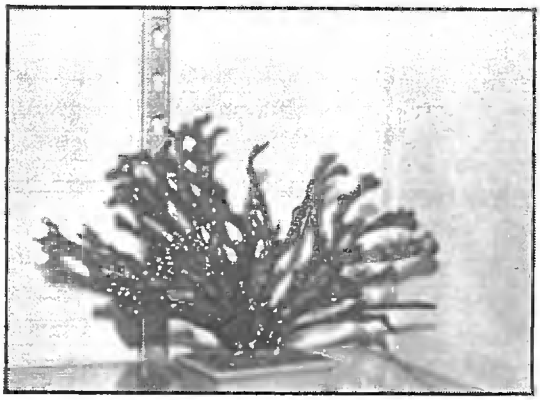


Figure 316. An exquisite antler specimen of Ling Chi featured in a Chinese mushroom museum.

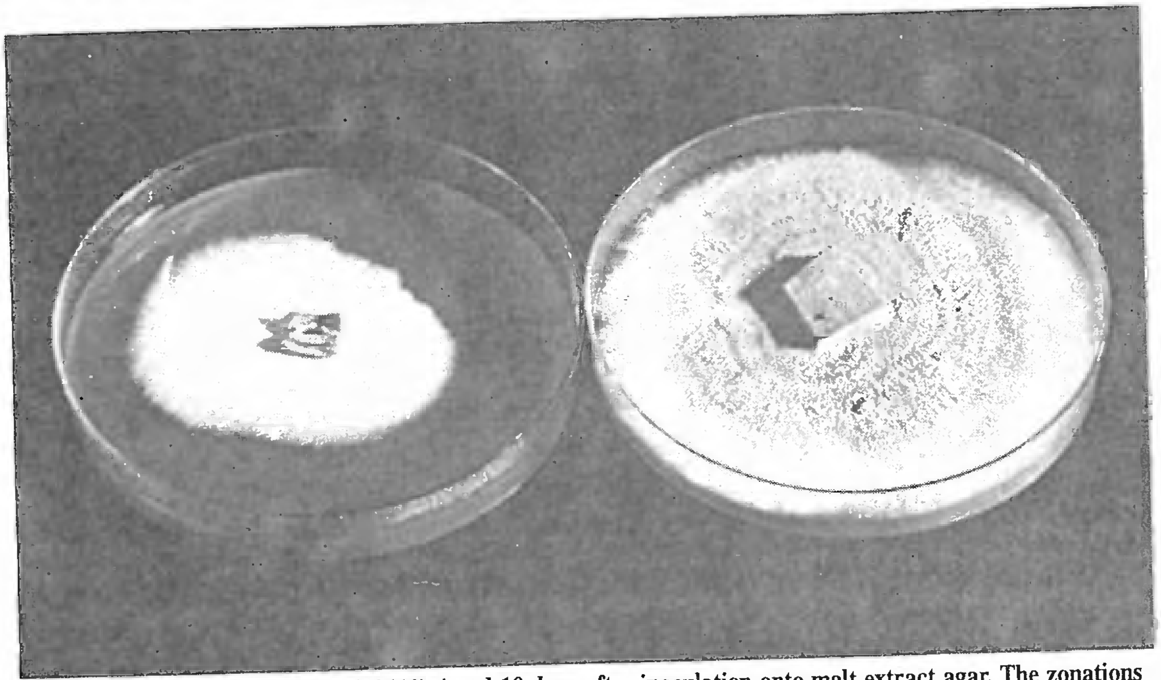


Figure 317. *G. lucidum* (ATCC #52412) 4 and 10 days after inoculation onto malt extract agar. The zonations are a strain-specific feature.

develops, the spore producing underlayer—the hymenium—is white and can be drawn upon. As the pores are crushed, a browning reaction occurs, thus allowing the artist to sketch an image.

Common Names: Reishi (Japanese for Divine or Spiritual Mushroom)
Ling Chi, Ling Chih, Ling Zhi (Chinese for "Tree of Life" mushroom)
Mannentake (Japanese for "10,000 Year Mushroom", "Mushroom of Immortality"
Saiwai-take (Japanese for Good-fortune Mushroom)
Sarunouchitake (Japanese for "Monkey's Seat")
The Panacea Polypore

Taxonomic Synonyms & Considerations: *Ganoderma lucidum* is the type mushroom, the pivotal species around around which the genus concept is centered. *Ganoderma lucidum* grows on oaks, and other hardwoods whereas two close relatives, *G. tsugae* and *G. oregonense*, grow primarily on conifers. *G. tsugae* grows on hemlocks, as its name implies, while in the southwest of North America, this species has been reported on white fir, *Abies concolor.* In culture, *G. lucidum* and *G. tsugae* develop long stems in response to manipulation of the environment. *G. oregonense* can be found on a variety of dead or dying conifers, including *Tsuga*. Knowing how mutable the formation of the stalk is under different cultural conditions, and that *Ganoderma lucidum* readily fruits on a variety of conifer and hardwood sawdust mixtures, delineation of these individuals based solely on habitat seems highly suspect.

Figure 325. Some strains will not form stems if carbon dioxide is maintained at atmospheric levels. White margin denotes new growth.

cap development can begin.

In its natural habitat, this change is analogous to the stalk emerging from the rich carbon dioxide environment below ground level. Once the CO_2 sensitive stalk emerges into the open air, the photosensitive, spore producing lateral cap develops. The caps form above the plateau of the ground and orient towards directional light. An indication of new growth is the depth and prominent appearance of a white band around the cap's edge. Under these conditions, cap formation is rapid and the time of harvest is usually indicated by the lack of new margin growth and the production of rusty brown spores. The spores, although released from below, tend to accumulate on the upper plane of the cap.

The cultivator has two alternatives for eliciting conk development once antlers have begun to form. The plastic bag can be left on or stripped away from the mass of mycelium/ wood chips/sawdust. If the protective plastic is removed and a fog-like environment does not prevail, massive evaporation will halt any fruitbody development. If the exposed block is maintained in a fog-like environment within the growing room, vertical stalk growth slows or abates entirely and the characteristic horizontal kidney-shaped cap begins to differentiate. Like the stalk, the margins of new growth are whitish while the aged areas take on a shiny burgundy brown appearance.

Cultivators in Asia inoculate 1-2 liter cylindrical bags or bottles, narrowly closed at one end and stopped with a cotton plug. Once inoculated, the bags or bottles are stacked horizontally in a wall-like fashion. After 30-60 days, depending upon the strain, inoculation rate, and growing conditions, the cotton filters are removed. The small opening channels CO_2 stimulating stem elongation. This same opening is also the only conduit for moisture loss. From this portal, finger-like primordial shoots

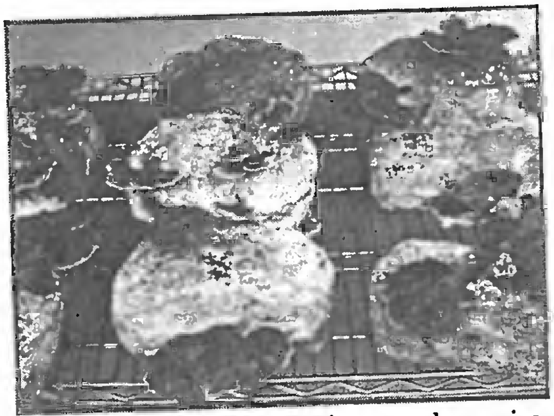
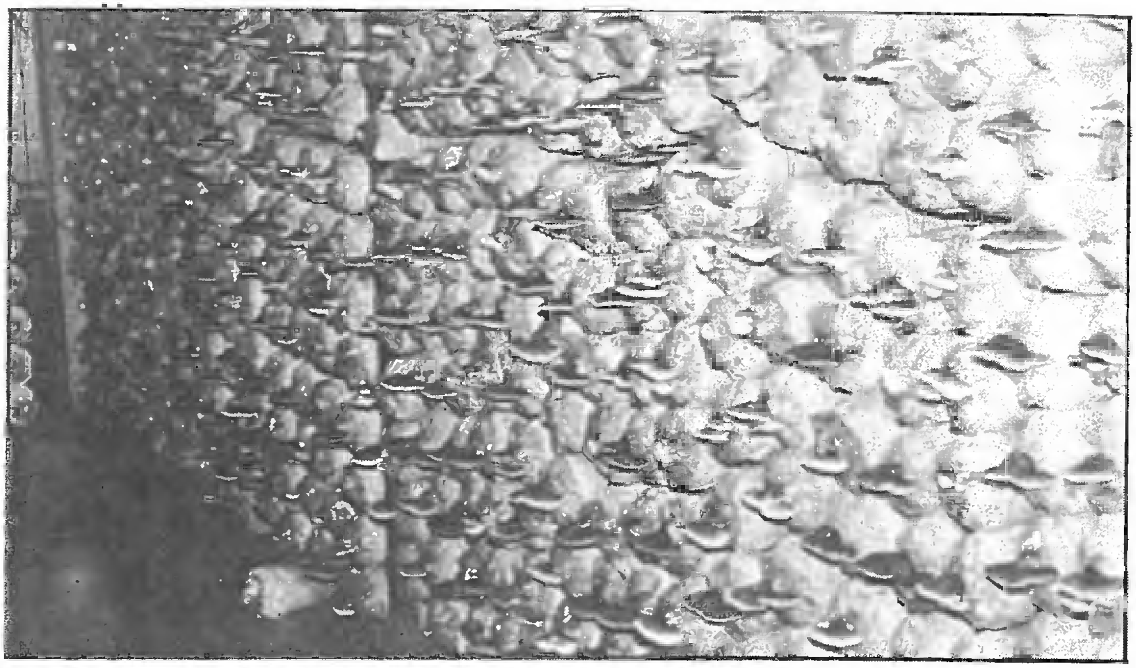
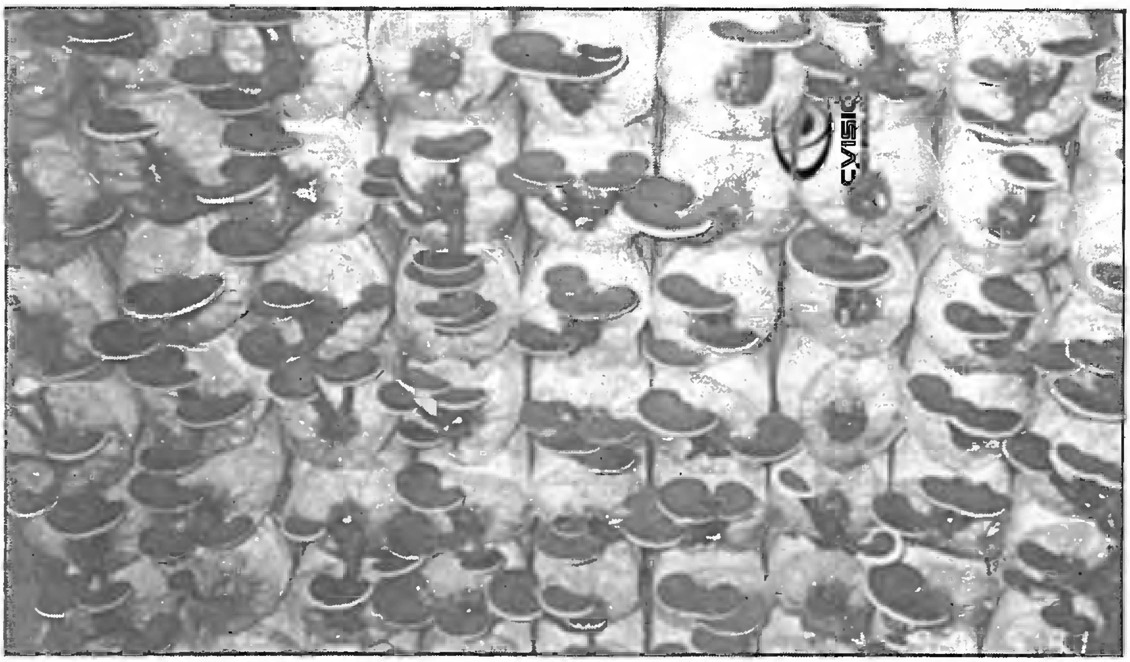
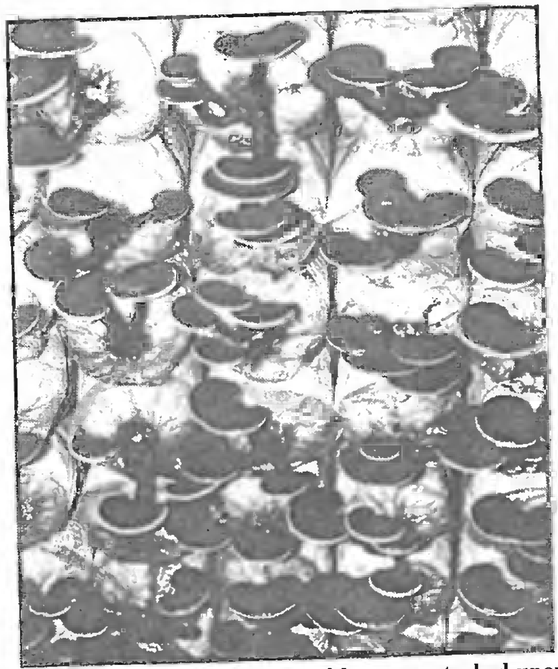


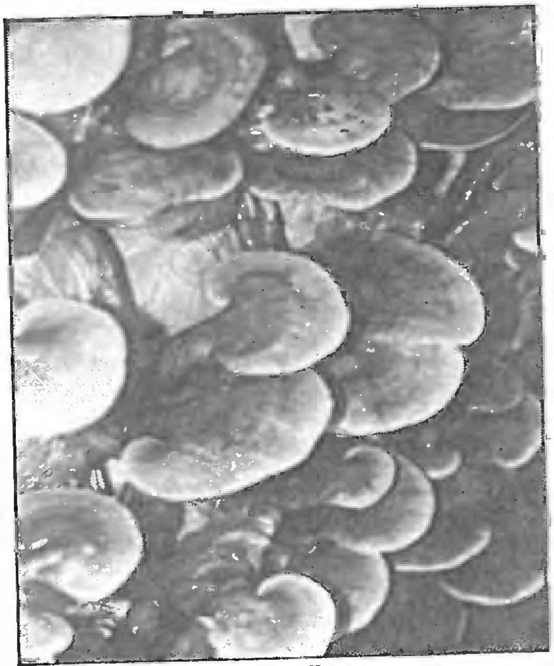
Figure 326. When the plastic is removed, exposing the mycelium, *G. lucidum* will only form when a condensing fog environment is maintained for a prolonged period.





Figures 327–328. In Asia, many cultivators fruit *G. lucidum* through the narrow opening of bags that once hosted the cotton filter plug. The plastic is left intact to help retain resident moisture.





Figures 329 & 330. Cylndrical bags are stacked upon one another to form a Reishi wall.

emerge into the high humidity environment of the growing room. With this method of cultivation, moisture is conserved and channeled to the developing mushrooms. Under low light conditions, stem elongation slows as the mycelium enters into the conk formation period. Cultivators of this method believe that the substantial substrate mass, protected from evaporation, produces better flushes than from a substrate exposed to the open atmosphere. With this second strategy, a condensing fog environment is not as critical as when the substrate is fully exposed to the air. Furthermore, contamination is less likely. Hence growers in Thailand are successful in growing *G. lucidum* in growing rooms featuring gravel floors and equipped with a minimum of environmental controls.

With either rapid cycle method, the cultivator can grow the archetypal form of *Ganoderma lucidum*, one long favored by the Chinese, Japanese, Koreans and Thai peoples. From time of inoculation to time of harvest is less than 3 months. If only antler-shaped fruitbodies form, yields are approximately 1/4 of the yield seen if caps are encouraged to form and mature. Should the cultivator's goals be solely that of yield and the development of the stalk is not desired, then yet another approach is recommended.

Five pounds of moistened hardwood sawdust/chips (60-70% moisture) are filled into the autoclavable, spawn plastic bags. The bags with their tops folded over are loaded into the autoclave and sterilized. After sterilization, approximately 100-150 grams of rye grain spawn is inoculated into the bags subsequent to autoclaving. Each is heat sealed. Colonization is characteristically rapid and complete in 10-20 days. After 30 days, the blocks are removed to the growing room whereupon the plastic is perforated. I use four bladed stainless steel arrowheads mounted on a board. The bags are

Growth Parameters

Spawn Run:

Incubation Temperature : 70-80° F. (21-27° C.)
Relative Humidity: 95-100%
Duration: 10-20 days
CO_2: tolerated up to 50,000 ppm or 5%
Fresh Air Exchanges: 0-1
Light Requirements: n/a

Primordia ("Antler") Formation:

Initiation Temperature: 65-75° F. (18-2°4 C.)
Relative Humidity: 95-100%
Duration: 14-28 days
CO_2: 20,000-40,000 ppm
Fresh Air Exchanges: 0-1
Light Requirements: 4-8 hours at 200-500 lux.

Primordia ("Young Conk") Formation:

Temperature: 70-80° F. (21-27° C.)
Relative Humidity: 95-100%
Duration: 14-28 days
CO_2: 5000-2000 ppm
Fresh Air Exchanges: As required for maintaining desired CO_2
Light Requirements: 12 hours on/off at 500-1000 lux.

Fruitbody Development

Temperature: 70-80° F. (21-27° C.)
Relative Humidity: 90-95%
Duration: 60 days
CO_2: < 2000 ppm
Fresh Air Exchanges: As required
Light Requirements: 12 hours on/off 750-1500 lux.

Cropping Cycle:

Two crops in 90-120 days.

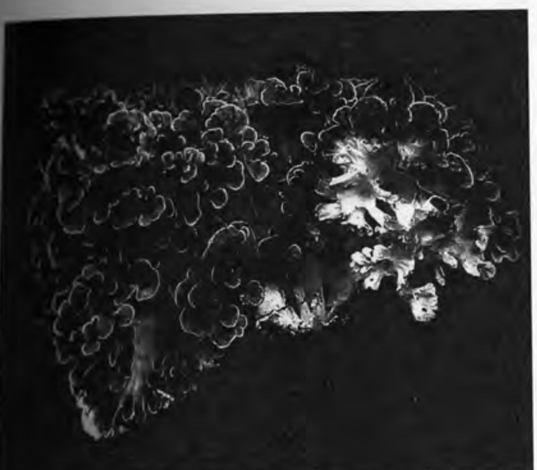
never opened. Each one is forcibly slammed downwards into the arrowheads. These "+" shaped slits become the sites for fruitbody formation. The bags are placed in the growing room and harvests of stem-less conks usually begin within a month. See Figure 325.

Recommended Courses for the Exponential Expansion of Mycelial Mass to Achieve Fruiting: There are several courses for expanding the mycelium to the fruiting stage. Each step results in an

Hardwood sawdust (3 parts fine: 1 part coarse) - 75%
Wheat bran, not refined - 23%
Sucrose - 1%
Lime and/or gypsum - 1%
Moisture content - 60-63%
pH 5.5-6.5

Hardwood sawdust (3 parts fine: 1 part coarse) - 80%
Wheat bran, coarse - 18%
Lime - 1%
Sucrose - 1%
Soil, hardwood forest (surface), dry wt. 10% (of the above mixture)
Moisture content - 60-63%
pH 5.5-6.5

Hardwood sawdust (fine 40%, coarse 20%)
Spent sawdust substrate - 20% dry weight
Wheat bran (coarse) - 10 %
Hardwood forest soil - 10% dry weight
Moisture content - 60-63%
pH 5.5-6.5



N.10 - *Grifola frondosa*, in its exquisite and delicious wild form.

HERICIUM ERINACEUS (Bull.) Pers.

Lion's Mane, Monkey's Head, Sheep's Head, Bear's Head, Old Man's Beard, Satyr's beard, Pom Pom, Houtou

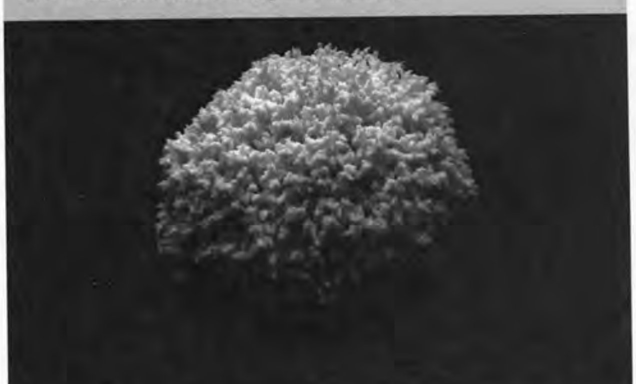
SPORES: 4-5.5x5-6.5 μm, elliptical/subglobose, amyloid, smooth/minutely roughened, white. **FRUITING BODY:** 8-40 cm across, unbranched, white/yellowish. Flesh white, not bruising when cut. **TEETH:** 1-6 cm, soft, white/yellowish.

RANGE: North America, Europe, Japan, China. **ECOLOGY:** Saprobic and parasitic white rotter on hardwoods (oak/walnut/beech/maple/sycamore logs/stumps). **GROWTH HABIT:** A single clump of dangling spines. **SEASON:** Summer-fall.

EDIBILITY: Delicious - taste and texture of crab. 31% protein, 17.6% carbs, sodium, phosphorus, iron, calcium, potassium, magnesium, thiamin, riboflavin, calciferol, niacin. **MEDICINAL:** Produces erinacines and hericiones with strong nerve growth factor stimulators. Helps rebuild myelin, increase cognitive ability, repair neurological trauma/degeneration, and may mitigate Alzheimer's and Parkinson's. Anticancer (gastric, stomach, liver), antibacterial, anti-Candida, anti-inflammatory.

CULTIVATION: Slow on agar, forming neuron-like pattern. LC is preferred inoculum. Mycelium not strong. Readily fruits on grains. Often hearty once established on nutrified sawdust (maple, oak, beech, elm, walnut, sycamore)—keeps popping out fruit bodies every few weeks. Does well on mycotems (partially buried logs). The related *H. americanum* grows similarly but is branched. *H. abietis* grows on conifer wood.

N.11 - *Hericium erinaceus* in a glacier-like cascade.



N.12 - *H. coralloides*, a close relative of *H. erinaceus*, is also edible.

N

Pholiota nameko (T. Itô) S. Ito & S. Imai

Nameko, Butterscotch mushroom

Spores: Brown/cinnamon-brown/rusty-brown. **Stalk:** 5-7 cm, with a yellow annulus on upper part. **Cap:** 5-8 cm, smooth with slimy coating. **Gills:** Attached, not decurrent, white/yellow/rust/ochre.

Range: Highlands of China and Taiwan, not known in Europe or North America. **Ecology:** Hardwood stumps/logs (oak/beech/chestnut/maple). **Growth Habit:** Large clusters. **Season:** Spring-fall.

Edibility: Choice. Common in traditional miso soup recipes, 20.8% protein, 4.2% fat, 66.7% carbs, 6.3% fat, thiamin, riboflavin, niacin, calcium, potassium, iron, sodium. Slime on cap disappears upon cooking. **Medicinal:** Anticancer, anti-inflammatory.

Cultivation: Easy and common. Substantial fruitings possible on conifer sawdust with 15% bran. To initiate orange slime layer formation, increase light, mist frequently, and lower temperature and CO2. Casing helpful, but adds dirt to sticky cap. To encourage second flush, rough the casing surface. Good for hardwood stumps/logs (beech/poplar/alder/aspen/oak/eucalyptus/maple/beech/poplar) that are partially buried.

C15 - *Pholiota nameko* is commonly cultivated in Asia.

Pleurotus ostreatus (Jacq.) P. Kumm. & Allies

Pearl Oyster, Japanese: *hiratake, tamogitake,* Chinese: *hao gu,* Czech: *hlíva,* Dutch: *oesterzwam,* Finnish: *vinoka,* French: *oreillette, couvrosse, pleurote en huître,* German: *austernseitling,* Italian: *orecchione gelone, agarico ostreato,* Japanese: *hiratake.* Polish: *boczniak ostrygowaty,* Russian: *vyeshyenka obiknovyennaya,* Spanish: *pleuroto ostreado,* Swedish: *ostronskivling*

Spores: 8-9x3-4 µm, oblong/elliptical, smooth, not amyloid, white. **Stalk:** 0.5-5x1-2 cm, stout, off center/lateral, solid, firm, dry, hairy/downy at base. **Cap:** 4-20 cm, oyster/fan-shaped, convex/plane/funnel-shaped, smooth, slightly lubricous if moist, not viscid, white/bluish-gray/grayish-brown/tan/dark brown/yellowish, often wavy/lobed, odor and taste mild. Flesh firm, white, soft. **Veil:** Absent. **Gills:** Decurrent (if stalk is present), close, broad, white/grayish/yellowish.

Range: Worldwide in temperate zones, North America, Asia, Australia, Europe. **Ecology:** Low valleys, on hardwood logs/stumps (elm/willow/aspen/beech/cottonwood/alder/sycamore/oak/tanoak), rarely on conifers. **Growth Habit:** Usually in shelving and overlapping rows/columns. **Season:** Spring and late fall.

Edibility: Y - mild and delicious, 10-30% protein, vit. C, niacin, folic acid, potassium. Check gills for insects. **Medicinal:** Produces lovastatin (concentrated in spores>gills>cap), which helps lower cholesterol. Antibacterial, strengthens veins and relaxes tendons, effective in the treatment of lumbago, numbed limbs, and blood vessel discomfort, antitumor, nerve tonic, antioxidant, anti-inflammatory, antiviral (HIV, common flu, hepatitis C), antacid properties. One of its glucans is the anticancer pleuran. **Dyes:** Ammonia+iron pot=gray green. **Remediation:** Heavily researched, highly regarded. Exuded metabolites are a nematode tranquilizer. Effective against many aromatic compounds (e.g. petroleum products, benzopyrenes, nerve agents, dioxins, PAHs, PCBs, TNT). Concentrates cadmium and Mercury (65-140x). Potentially able to create a type of fuel. **Other:** Its prolific spore load causes allergic reactions in some people.

Cultivation: The go-to beginner mushroom. Adaptive, tolerant of stress/competitors, wide ranging appetite (grows on 200+ waste streams). Does well on stumps and partially buried logs. Grows well on straight straw as well as with supplementation. The closely related *P. pulmonarius* (Phoenix Oyster) prefers warmer temperatures and some strains can grow on conifers—it is very fast growing and tenacious. The colorful Pink Oyster (*P. djamor*) and Golden Oyster (*P. citrinopileatus*) are very quick growing and prefer warmer temperatures. The King Oyster (*P. eryngii*) is much more robust and meaty—it is commonly cultivated in sets of two fruit bodies from nutrified sawdust in bottles. Example fruiting formulas for *P. ostreatus:*

Cotton seed hulls - 97%
Gypsum - 2%
Lime - 1%

Rice straw - 80%
Cotton waste - 18%
Gypsum - 1%
Lime - 1%

Water hyacinth - 80%
Cereal straw - 17%
Gypsum - 2%
Lime - 1%

C

Nutrified Sawdust Kits

Sawdust kits designed for indoor fruiting contain supplementation and are typically pressure cooked in polypropylene filter patch bags, cooled, and then inoculated under aseptic conditions. Many farms prefer using jars as fruiting containers for this substrate, typically for King Oyster, Reishi, and Enoki, as well as other species.

Mixing and Hydrating Nutrified Sawdust

Below is a standard formula (by volume) for nutrified sawdust spawn. To elaborate on this basic recipe, refer to the section *Substrate Formulation*.

- 10 parts hardwood sawdust *OR* 5 parts sawdust and 5 parts wood chips
- 2 parts oat, rice, or wheat bran
- 1 part gypsum

Thoroughly mix the dry ingredients on a wire screen or in a substrate tumbler, then slowly hydrate the mixture to bring it up to field capacity. This watering process is essentially the same as for pasteurized sawdust. One notable difference is that the bran and gypsum quickly retain more water than plain sawdust, decreasing the time needed to wait for adequate hydration. Properly hydrated nutrified sawdust should feel light, fluffy, moist, but not too wet. When it is firmly squeezed it should produce a short stream of water, not just a couple drops. This extra water holding capacity of nutrified sawdust also contributes to the increased yield obtained from this substrate.

Once the nutrified sawdust is properly hydrated it is then loaded into jars or filter patch bags. Filling a large number of bags can be facilitated by a using a standardized scoop or with a substrate tumbler with a lid modified for loading. Five to six pounds (2.25-2.75 kg) of substrate is a standard weight per bag. Weighing each bag after loading ensures consistency and helps to track biological efficiency. Once the bag is filled, wipe down the upper, inner portion of the bag if it is dirty. This reduces the risk of contamination during inoculation.

On Nutrified Sawdust Ingredients

Wheat, oat, and rice bran are commonly used nitrogen sources. If you have the means, adding 25-50% hardwood chips to the substrate mix can extend the life of the kit as well as increase yields. Woodchips should be soaked overnight prior to mixing, so as to hydrate them. Gypsum is a commonly added mineral supplement. Adding a substance with a high capacity for water retention can also help increase yields. One study found that replacing 20% of nutrified sawdust with hydrated biochar had no impact on yields.[16] The production of biochar is discussed in Chapter 9.

Sterilizing Nutrified Sawdust

Once kits are loaded, they are closed and sterilized using one of the methods described earlier. Similar to pasteurized bags, I prefer to expel the air from the bag, roll down the top and tie it off with the ends of the rolled top. Rolled as such, sterilized bags can be stored for extended periods of time and moved between workspaces with reduced concern of contamination.

The 3-8 bags that fit in a standard pressure cooker should be sterilized at 15 psi for 2-3 hours. A 55-gallon drum retrofitted with racks can hold 25-35 nutrified sawdust bags. With the drum lid in place, but not sealed, the bags are then steamed ("ultra-pasteurized") in the drum for 8-10 hours to sterilize them. This steam can be produced from 7 inches (18 cm) of water in the bottom of the drum, or it can be piped in from a pressure cooker or another metal drum. These kits can also be tyndallized for 2 hours at a time on 3 sequential days.

55-gallon drums can also be modified with pressure regulating systems and used as a large autoclave. These drums can only maintain a pressure of around 3 psi, which cuts cooking time down to 6 hours. A drum lid can also be rigged with a pressure gauge and petcock. This low-cost, low-pressure autoclave must be monitored as the drum could potentially blow up if left unattended!

Loading shelves with nutrified sawdust kits. Lid rings pad each bag to ensure good air flow. The sterilizing drum is insulated while cooking to reduce fuel inputs.

Inoculating and Incubating Nutrified Sawdust Kits:

Nutrified sawdust must be inoculated under aseptic conditions. As inoculating many tall bags in a small glove box can prove challenging, this is one process that greatly benefits from the use of a flow hood.

Materials

- Jar of myceliated grain spawn
- 5-pound bag of sterilized and cooled nutrified sawdust
- Wire, impulse sealer, or electric food preservation sealing preserving unit

Method

1. Shake the grain jar to break up the grains.
2. Under aseptic conditions, open the sawdust bag and grain jar.
3. Quickly pour approximately 1 tablespoon of myceliated grains into the sawdust bag without placing your hands over the opening of the bag. Rolling the jar while you pour helps the grains easily fall out of the jar.
4. If using a flow hood, fill the bag with a plenum of air.
5. Seal the bag. This can be done by simply rolling down the bag and tying it with a piece of stiff wire. For larger operations, bags can be quickly sealed using a heating element such as those in an impulse sealer or food preservation unit. Check for a proper seal by gently squeezing the bag and listening for a hiss. Reseal the bag or patch any holes with tape if needed.
6. Shake the bag to distribute the grains.
7. Label with date and species/strain and set to incubate.

With the additional nitrogen, around 1 tablespoon of grain spawn is all that is needed to inoculate these kits. In front of a large flow hood, an assembly line can be set up with multiple people to increase the efficiency of this repetitious process. Nutrified kits are incubated standing up and with a slight air gap between them to minimize overheating.

(Above) Closing bags with stiff wire is a good option when working in a glove box or other constricted space.

(Right) A flow hood and impulse sealer enable quicker work when doing a large number of bags.

8

Putting it All Together

The following are two simple routes that I commonly take to combine the above concepts and skills and also avoid a lot of the labor involved in the cultivation process.

Cheap and Easy Bulk Spawn

Inoculate liquid media outside of a transfer space by taking a biopsy of a mushroom. Inoculate grains with the LC and spawn these grains to pasteurized sawdust. This is the simplest, cheapest means for producing a consistent supply of high quality and vigorous spawn for outdoor installations. If all materials are cooked, tyndallized, and pasteurized with solar heat, a pressure cooker and aseptic environment can be avoided.

All-in-One Fruiting Spawn

A filter patch bag can be modified to receive LC by applying a thick blob of RTV silicone. Once the silicone has cured, cover the blob with packaging tape to ensure that it does not fall off. Fill the bag with 5-6 pounds (2.25-2.75 kg) of nutrified sawdust and place 2 tablespoons of freshly cooked grains just below the LC injection site. Close the bag and pressure cook it for 2 hours at 15 psi. Once cooled, seal the bag in the transfer space and then inoculate with 30-180 milliliters of LC. Once the grains are myceliated the contents can be shaken and then set to incubate. This practice can also be applied to 0.5 gallon (2 L) mason jars, which do not necessitate aseptic closure after heat treatment and thus avoid the transfer space entirely. Fruiting from these All-in-One LC-inoculated, nutrified sawdust filled jars is arguably the easiest and most effective means for creating an abundance of high quality yields from some of the most popular cultivated mushroom species. I recommend this route to anyone who wishes to establish a low-input mushroom cultivation operation. Further, this practice can readily extend to species that are cultivated for their edible and/or medicinal sclerotia: *Polyporus umbellatus, Lignosus rhinoceros, Omphalia lapidenscens, Pleurotus tuber-regium, Wolfporia extensa,* and *Xylaria nigripes.*

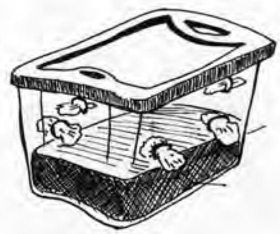
(Left) These All-in-One jars are one of the most efficient and effective ways to grow edible and medicinal mushroom year-round with minimal cultivation infrastructure. After being filled with nutrified sawdust and grains, the jars can be sterilized en masse in a 55-gallon drum, cooled, then inoculated outside the lab with a liquid culture syringe.

(Below) Depending on the cultivator's goals, the various stages in the traditional cultivation methodology each have their place, but not all are necessary to produce edible mycelium and fruit bodies.

Common Options for Small Fruiting Spaces

- **In vitro:** Many species will begin to fruit in their container, signaling to the cultivator that they should be moved to a fruiting space. If these fruit bodies are allowed to mature in the bag, the need for a fruiting space is eliminated. Mushrooms grown in these high CO_2 environments often develop malformed fruit bodies, an unappealing trait. This discreet, low-input practice is commonly used with Reishi and *Psilocybe cubensis* where the appearance of the mushroom is not as great of a concern. Filter patch bags equipped with a high micron filter or, better yet, a large filter size will facilitate healthy fruit body maturation of other species *in vitro*.
- **Bathrooms:** The humidity of a bathroom makes for an easy and natural fruiting environment for species that can tolerate swings in humidity. Oysters fruiting from towering buckets or hanging bags of coffee and/or straw are nice additions to any modern bathroom.
- **The plastic tent:** This simple fruiting chamber is commonly used for the casual cultivator seeking to fruit one or two sawdust blocks or straw kits/buckets. Here, a plastic bag or piece of plastic sheeting is tented over the fruiting kit to hold in moisture. Fresh air is provided through slits or small holes cut in the plastic. Humidity is maintained by spraying the inside of the bag (but not the mushrooms) as needed to maintain slight condensation on the bag's interior. The kit and bag are placed in an appropriately heated space and light is provided with any of the suggested sources.
- **Outdoor microclimate:** Shaded outdoor areas that supply adequate humidity can often support the maturation of mushrooms on fruiting blocks or containers. Designing these spaces is discussed in Chapter 9.
- **Shotgun fruiting chamber (SGFC):** A large plastic tub is drilled over its entire surface with 0.25-inch (0.6 cm) holes spaced 2 inches (5 cm) apart in all directions. These holes allow for passive air exchange while retaining a high humidity level. Extra humidity can be provided by perlite or biochar that has been fully hydrated by being submerged in a pot of water for a few seconds and then drained in a colander. Once excess moisture has stopped dripping, the perlite/biochar is then used to fill the bottom 5 inches (12 cm) of the plastic tub. Fruiting kits or trays are placed on top of the perlite and the lid is closed. The perlite/biochar releases moisture, providing humidity. The walls of the tub may need to be misted occasionally to maintain proper humidity levels.[24]

- **Monotub:** In this set-and-forget system, substrate is directly inoculated with grain spawn in the bottom of a plastic tub that has been fitted with several 1-inch (2.5 cm) holes. After inoculation, the tub's lid is set in place and not removed until harvest. During myceliation the holes are covered with duct tape or a similar material to retain moisture and keep CO_2 levels high. Once the substrate is myceliated, the tape is removed and the holes are then plugged with fiberfil to provide an influx of fresh air. The number of holes and the amount of fiberfil used varies by climate and season. Often, all that is needed is just enough fiberfil to keep dust and bugs out. However, if the humidity does not stay high enough in the tub, more fiberfil should be used. Holes are located along the substrate layer and at the top of the container to provide a natural current of fresh air coming in from the top while the heavier CO_2 exits at the substrate level. This system works well for compost-loving species as well as for the species that can be spawned to pasteurized, plain sawdust. Nutrified sawdust should not be used in a monotub as it is likely to contaminate. The lids of monotubs can be modified with a clear piece of glass to facilitate viewing and LED light strings can be added to the inside of the lid to create an all-in-one fruiting environment. Some cultivators mix a saturated and sterilized water holding substance such as coconut coir, vermiculite, or biochar with the substrates at spawning to increase the water content in a monotub and its subsequent yields. This is known as the *rez effect*.



PF Tek

In 1992, Robert McPherson (a.k.a. Professor Fanaticus) introduced the PF Tek, a simple means for growing *Psilocybe cubensis* using little more than some canning jars, vermiculite, brown rice, and a few spores. This technique significantly lowered the perceived level of skill required to successfully grow mushrooms at home. In the years since its introduction, the PF method has been highly elaborated upon by cultivators around the world, each with their own preferred tweak to the tek. Assuming that the reader has a firm grasp of the cultivation concepts above, I lastly present the PF Tek in a summarized format for the sake of thoroughness and, well, because it's just so ridiculously easy.

Materials

- Half-pint (250 mL) canning jars
- Aluminum foil
- Brown Rice Flour (BRF) (store bought or homemade in a coffee grinder)
- Canning jar lids with 4 holes poked out with a hammer and nail
- Spore syringe
- Tool sterilizing materials
- Vermiculite

Method

1. Hydrate the vermiculite to field capacity. Slowly, evenly, and thoroughly mix in the BRF. The preferred ratio of ingredients is 2:1:1 (verm:H_2O:BRF). For 5 jars, 2 cups (500 mL) vermiculite, 1 cup (250 mL) water, and 1 cup BRF is adequate.
2. Fill the jars with this mix to within 0.5 inches (1.25 cm) of the top. Clean this upper part of the jar thoroughly and then top jars off with dry vermiculite. This vermiculite serves as a crude air filter.
3. Cover each jar with a punctured lid and foil.
4. Pressure cook the jars at 15 psi for 60 minutes OR steam them in a pot with a heavy lid for 90 minutes. Allow the jars to cool overnight.
5. Under aseptic conditions, inoculate each hole in the lid with 0.25 mL from a spore syringe or liquid culture syringe, replacing the foil or substituting with micropore tape once inoculated. Be sure that the needle is sterile. Many people have success inoculating their jars in a clean bathroom.
6. Incubate the jars until they are fully myceliated. After full myceliation, allow the jars to sit for another week to further condense.
7. Open each jar and knock the "cake" out to "birth" it. Dunk the cakes in cold water for 12-24 hours.
8. Roll the cakes in dry vermiculite and place them in a fruiting space.
9. At harvest, make a spore syringe and repeat.

Cakes typically flush 3-4 times. Yields are increased if the cakes are dunked for 12 hours between flushes. PF cakes can be used as spawn for higher quality substrates such as compost or manure. Shiitake, Oysters, and other mushroom species have been successfully fruited from PF cakes, often with a low BE relative to more robust substrates. If biochar is used in place of vermiculite, this technique presents a very simple, low-cost means for producing small amounts of mushrooms.