Pennsylvania Biological Survey (PABS)
Mycological Technical Committee (MYCO-TC)

The Importance of Fungi

13 ESSENTIAL WAYS FUNGI SHAPE OUR WORLD

Table of Contents

This booklet is a product of the **Pennsylvania Biological Survey's (PABS) Mycological Technical Committee (MYCO-TC)**.

pabiologicalsurvey.org

CREDITS

Contributing Authors
Barbora Batokova
Stephen Bucklin
Jerry Hassinger
Hannah Huber
Richard Jacob
Marion M. Kyde
Sarah L. Bashore
Ella Serpell
Scott Stoleson
David Wasilewski

Project Lead
Jerry Hassinger

Technical Edit
Hannah Huber

Editorial, Design, & Production Lead
Barbora Batokova

THANK YOU

Our gratitude goes to everyone who contributed their time, expertise, and creativity to make this publication possible. Special thanks to Dr. Barrie Overton and Dr. Gary Emberger for their review.

NOTE

In some cases, generative AI was used to extend the background of images to fit the desired format—never to alter the subject of the photo.

About PABS

The Pennsylvania Biological Survey (PABS) is a non-profit, all-volunteer organization dedicated to understanding and conserving the natural biological diversity of the Commonwealth. Among its responsibilities, PABS evaluates the conservation status of wild species—whether endangered, threatened, or otherwise of concern—across animals, plants, fungi, and other organisms in the state.

Its more than 150 members (including over 70 PhDs) include scientists from across the state, representatives of state and federal natural resource management agencies, staff from major natural history museums and scientific institutions, and other knowledgeable contributors. PABS is governed by a Steering Committee and works through a series of technical and standing committees focused on specific species groups or program areas, such as the Mycological Technical Committee (MYCO-TC).

About MYCO-TC

Mission

Conservation of fungi, including lichens, informed by scientific data to serve the public's interests.

Vision

Fungi conservation informed by scientific data to comply with Article I, Section 27 of the Pennsylvania Constitution, known as the Environmental Rights Amendment.

Overarching Goals

1. Communicate the importance of fungi (including lichens) and promote their conservation.
2. Support fungal diversity research and species conservation status assessments within the state.
3. Increase the scientific and conservation contributions of forays and community scientists.
4. Assist the Pennsylvania Department of Conservation and Natural Resources in implementing best management practices for wild fungi.
5. Continually support the curation of the official state checklist of Pennsylvania fungi.

Photo by Barbora Batokova

Commonly known as the **old man of the woods**, *Strobilomyces* is a genus of distinctive boletes with shaggy to scaly caps and woolly stems.

Introduction:
The Importance of Fungi

By Jerry Hassinger and Hannah Huber

Annual Review of Environment and Resources: **Pushing the Frontiers of Biodiversity Research: Unveiling the Global Diversity, Distribution, and Conservation of Fungi**

4.3. Advancing Fungal Research and Conservation

"Although efforts to fill the large gaps in our knowledge of fungal diversity and distribution need to continue, the key objective in fungal conservation today should be to raise scientific, public, and political interest and awareness of fungi and their vital roles that benefit people, nature, and the climate. Ultimately, public awareness and appreciation of biodiversity set the foundation for conservation to take place. The increasing public interest in fungi, thanks to committed mycologists and their organizations together with recent popular science books, series, short videos, TED Talks, documentaries, podcasts, and other media, may help conservation as much as improved science."[1]

1 Tuula Niskanen et al., "Pushing the Frontiers of Biodiversity Research: Unveiling the Global Diversity, Distribution, and Conservation of Fungi," *Annual Review of Environment and Resources*, vol. 48 (November 2023): 149–176, https://doi.org/10.1146/annurev-environ-112621-090937

Recognizing Fungi as Their Own Kingdom

Until 1969, fungi were classified as "lower plants." However, accumulating research showed that fungi are neither plants (flora) nor animals (fauna), leading to their recognition as a separate Kingdom in the tree of life. In 2018, scientists (including Giuliana Furci) proposed the term "funga" to give fungi equal representation alongside flora and fauna in conservation, legislation, and education. The term has since been steadily gaining traction.

The funga of Pennsylvania includes thousands of species that form mushrooms and ascocarps, thousands of microfungi, and hundreds of lichenized fungi. New species are continually discovered. Yet, more than 50 years after fungi were recognized as separate from plants, most natural resource and conservation references still mention "flora and fauna" only.

Most states offer fungi no legal protection, and on the US Endangered Species List, as of 2025, there are only two species of lichenized fungi compared to over 700 plants and roughly 500 animals. This is not because fungi are unthreatened, but because fungi simply haven't been prioritized for study. Over 90% of estimated fungal diversity worldwide has yet to be discovered.

Fungi are often brushed off as "cryptic," and their mycelium, often hidden in substrates, can be more difficult to measure than a plant root system. Hence, fungi are often referred to as the "hidden Kingdom." However, the advent of molecular techniques have greatly aided mycological research and for many, exploration of fungi offers a new lens with which to observe ecosystems and understand how the world works.

A Needed Shift in Focus

In the United States, edible mushrooms receive the most public attention among wild fungi. Beyond that, so-called "bad" fungi—such as pathogens and toxic species—are the primary focus of research institutions, resource managers, farmers, homeowners, and the healthcare system. For example, the global fungicide market was valued at $19 billion in 2024. Unfortunately, the focus on fungal pathogens has overshadowed the many beneficial roles of fungi and their conservation needs. As a result, we have a well-established community of pathologists, but conservation mycologists are rare or absent in most states.

For centuries, the beneficial aspects of fungi have remained hidden mostly due to our ignorance. Research has been uncovering these hidden values, but with little funding and trained human capacity, progress has only recently gained momentum.

The striking **pink fringed faery cup** (*Microstoma floccosum*) fruits on buried wood, recycling locked nutrients back into the forest soil as part of its role as a wood-decaying ascomycete. Its vivid, hairy-rimmed ascocarps highlight how visually conspicuous fungi can be, and yet most fungi remain overlooked in conservation planning and biodiversity assessments.

Mapping the Hidden Kingdom

A major breakthrough in understanding the global distribution and conservation status of fungi emerged with the launch of the **Underground Atlas** by SPUN (Society for the Protection of Underground Networks) in 2025. Built using more than 2.8 billion fungal sequences from 130 countries, the Atlas offers the first global visualization of mycorrhizal fungal diversity and endemism.

Pennsylvania is included in the map, and data suggest relatively high endemism of ectomycorrhizal (EM) fungi in regions such as Rickett's Glen State Park, which boasts an estimated 45–78 EM species per hectare, while showing low endemism for arbuscular mycorrhizal (AM) fungi. Unlike most global hotspots, fungal habitat at Rickett's Glen is largely protected as a state park.

The Atlas highlights gaps in fungal conservation worldwide (with over 90% of hotspots outside protected areas) and offers a baseline for states like Pennsylvania to monitor, refine, and communicate the importance of their funga. Referencing this global tool within Pennsylvania's conservation efforts marks a pivotal shift toward recognizing underground biodiversity as a critical layer in land management and environmental planning.

Purpose of This Booklet

Produced by the **Pennsylvania Biological Survey's** (PABS) **Mycological Technical Committee** (MYCO-TC), this booklet aims to almost exclusively shine the light on the beneficial aspects of fungi and present them as an indispensable natural resource and a major feature of our lives and landscapes. Understanding and appreciating the multiple beneficial aspects of fungi is the key to their conservation and the goal of this booklet.

We identified 13 categories of importance, which are not mutually exclusive. For instance, an edible mushroom species can also have medicinal values, plus it might be a plant partner, thus checking the boxes of three importance categories. We hope this booklet redefines and expands your perception of what fungi are, what they do, and inspires you to learn your funga to the level you know your flora and fauna. We welcome you to reach out to MYCO-TC along your journey.

Retiboletus ornatipes, or the **ornate-stemmed bolete**, is a striking bolete with a yellow, prominently reticulate stipe. It grows in hardwood forests of eastern North America, forming mycorrhizal partnerships with oaks and supporting nutrient exchange and forest health.

1. Fungi Benefiting Plants:
Symbiotic Mycorrhizal and Endophytic Fungi

By David Wasilewski

The roles of fungi in forest ecology are varied, ranging from nutrient recycling and soil formation to supporting plant resilience and maintaining biodiversity. Saprobic fungi are vital to the conversion of dead organic matter into nutrient-rich humus and eventually into topsoil that is held together by new generations of plant roots and fungal mycelium. Parasitic fungi form relationships with other organisms—plants, fungi, animals—often to the detriment of their associate. Such fungi are often viewed as destructive or—when infecting a human—dangerous. However, when viewed within the context of long-range forest ecology, it is likely that some parasitic fungi help to "weed out" plants that are weak or poorly suited to thrive within the ecosystem at hand. There are two additional groups of fungi which have co-evolved with plants, forming mutually beneficial relationships that enhance the survival and health of both partners. Mycorrhizal fungi interact with the roots of living trees. Ectomycorrhizal fungi enjoy symbiotic relationships with trees and other plants by engulfing roots in mycelium that allows the plant to more effectively absorb moisture and nutrients present in its surroundings. Other types of mycorrhizal fungi penetrate the roots of plants and assist in the transfer of nutrients between plant and fungus. Finally, endophytic fungi are microscopic organisms that live within a plant, between its cells.

These four categories—saprobic, parasitic, mycorrhizal, and endophytic—are not mutually exclusive. Some fungi function in more than one of these four roles. For example, the fungal species *Grifola frondosa*, which produces the popular edible mushroom **maitake**, is thought to operate as a parasite on an infected living tree. Once the tree

Sought after by foragers in the spring, the **half-free morel** *(Morchella punctipes)* leverages both mycorrhizal and saprobic lifestyle.

Brittlegills (*Russula* spp.) are common mycorrhizal fungi in Pennsylvania, forming symbiotic relationships with a variety of hardwood and conifer trees, aiding nutrient exchange and supporting forest health.

dies, this fungus feeds on the nutrients present in the tree's roots, becoming saprobic. Some species of *Morchella* (fungi that produce the popular edible morels) appear to be able to form mycorrhizal associations with the roots of trees, but can also fill a saprobic role, feeding on parts of dead plants.[1]

Mycorrhizal Fungi

"The future of the world's flora may depend as much, if not more, on what's below the ground as what's above. Beneath 90% of all plants lies an invisible support system—subterranean fungal partners that form a network of filaments connecting plants and bringing nutrients and water to their roots. In return, the plants provide a steady supply of carbon to the fungi. Now, researchers are learning that these hidden partners can shape how ecosystems respond to climate change."[2]

The Ecological Roles of Mycorrhizal Fungi

According to CID Bio-Science, mycorrhizal fungi contribute to forest ecosystems in five key ways:[3]

1. **Improve access to nutrients and water:** Mycorrhizal fungi enhance a plant's ability to absorb nutrients and water through multiple mechanisms. Some fungi form a sheath around plant roots, increasing the effective surface area and boosting the uptake of nutrients from the soil. Others grow into the root cells themselves, forming intimate connections that facilitate the direct exchange of nutrients between plant and fungus.
2. **Help in seedling establishment:** Fungal filaments (hyphae) penetrate the roots of young seedlings, providing them with access to vital nutrients, improving their chances of survival.
3. **Protect against pests and root pathogens**: A healthy, well-nourished plant is more resistant to infections, and mycorrhizal fungi offer additional protection by excreting enzymes that are toxic to soil-borne pests like nematodes.[4]
4. **Enhance resilience to environmental stress and climate change:** During periods of drought and other stressful conditions, mycorrhizal fungi help plants absorb moisture more efficiently, improving their ability to withstand environmental challenges.
5. **Maintain structural and species diversity:** By supporting plant health and nutrient distribution, mycorrhizal fungi play a crucial role in preserving biodiversity and maintaining ecological balance in forest environments.

Although scientific evidence exists to support these claims, ongoing research is needed to fully understand the extent of mycorrhizal fungi's impact. Also see article ***8. Sequestering Carbon.***

1 Ori, F., Hall, I., Gianchino, C., Iotti, M. and Zambonelli, A., 2019. Truffles and morels: two different evolutionary strategies of fungal-plant interactions in the Pezizales. In Plant microbe interface (pp. 69-93). Cham: Springer International Publishing.
2 Elizabeth Pennisi and Warren Cornwall, Hidden web of fungi could shape the future of forests, Science, 28 Aug 2020, Vol 369, Issue 6507, pp. 1042-1043
3 CID Bio-Science: 5 Ways Mycorrhizae Influence Forest Productivity. https://cid-inc.com/blog/5-ways-mycorrhizae-influence-forest-productivity/
4 Azcón-Aguilar, C.; Barea, J. M. (29 October 1996). "Arbuscular mycorrhizas and biological control of soil-borne plant pathogens – an overview of the mechanisms involved". Mycorrhiza. 6 (6): 457–464.

The **painted suillus** *(Suillus spraguei)* is considered host-specific because it forms mycorrhizal relationships almost exclusively with eastern white pine *(Pinus strobus)*.

Mainly recorded from the eastern United States, *Lactarius cinereus* seems to be a rare find in most places, Pennsylvania included.

The **downy rattlesnake plantain** (*Goodyera pubescens*) is a terrestrial orchid native to temperate North American forests. Its survival and growth depend on an obligate mycorrhizal association, primarily with fungi in the genus *Ceratobasidium*.

Ectomycorrhizal Fungi

Healthy temperate and boreal forest ecosystems rely on ectomycorrhizal fungi, which form mutually beneficial relationships with trees. In some cases, one fungal species may associate with more than one type of tree. One is apt to see many different brightly colored mushrooms representing genera *Russula* or *Amanita* dotting the floor of a forest that features a variety of types of trees. On the other hand, some mycorrhizal fungi are known to associate with only one species of tree. For example, the **painted suillus** mushroom *(Suillus spraguei)* is found only where white pine is present.

Conservation of Ectomycorrhizal Fungi

In the forests of Pennsylvania, several environmental challenges have emerged over the past several decades. The invasive **woolly adelgid** *(Adelges tsugae)* has significantly reduced the population of **eastern hemlock** (*Tsuga canadensis*). Presumably, this also presents a threat to any hemlock-associating fungal species. Thus, we see here an example of interdependence within the general concern of forest conservation. **American beech** *(Fagus grandifolia)* is another tree under threat in Pennsylvania. Beech is known to associate with a variety of mycorrhizal fungi, including *Lactarius cinereus*, which appears to associate primarily, if not exclusively, with beech.

Other Types of Mycorrhizal Fungi

Fungi that penetrate the roots of living plants fall into several different technical subcategories, and the functions of such fungi are varied. However, the primary feature is that they aid in the transfer of nutrients between plants and fungi, which generally benefits both entities. However, in some cases, the plant seems to be the primary benefactor. For example, most (if not all) species of orchids require the assistance of such types of mycorrhizal fungi, and without the fungi these orchids would cease to exist.

Endophytic Fungi

Embedded within the cellular structures of plants, microscopic species of fungi known as endophytes coexist harmlessly with their hosts. These fungi appear to provide protection, helping plants defend against potentially harmful insects, parasitic fungi, and various infections.

Until fairly recently, these fungi were presumed to occupy an ecological niche separate from the

While **maple trees** (*Acer* spp.) don't host more endophytic fungi than other temperate trees, research shows they harbor highly diverse endophytic communities compared to oaks, birches, or conifers.

Beneath the towering hemlocks of Cook Forest, a hidden network thrives—the so-called "Wood Wide Web," where fungi connect trees through intricate underground networks.

saprobic, mycorrhizal, or parasitic species of macrofungi that produce readily observable fruit bodies. However, modern analysis (most notably DNA sequencing) suggests that at least some endophytic fungi spend part of their life functioning as saprobic or parasitic entities.

Endophytic fungi are likely present in all plants:

"Endophytic fungi appear to be ubiquitous; indeed, no study has yet shown the existence of a plant species without endophytes. High species diversity is another characteristic of endophytic mycobiota which is depicted by the fact that it is quite common for endophyte surveys to find assemblages consisting of more than 30 fungal species per host plant species."[5]

Potential Uses for Endophytic Fungi

Having gained insight into the prophylactic nature of endophytic fungi, scientists have been studying their potential uses as pharmaceutical agents, as well as alternatives to synthetic insecticides and fertilizers.

Conservation of Endophytic Fungi

Given that much remains to be learned about endophytic fungi, their continued study represents an area of mycology offering abundant opportunities for fruitful research. Clearly, these entities should be prioritized within the list of concerns included in a program of conservation of fungi.

The "Wood Wide Web"

The mycelium of ectomycorrhizal fungi forms a vast interconnected network linking together trees and other plants that populate a given forest. Although much more research is required to understand how common mycorrhizal networks (the "wood wide web") function, it has been suggested that chemical impulses travel along this network, potentially facilitating a type of "communication" among plants and fungi.

For example, the hypothesis suggests that when a fungus within a plant's roots or tissues responds to an infection, this response could be received by neighboring plants through the web. While the wood wide web concept is relatively new to science, research that focuses upon the interconnectedness of organisms that inhabit our forests will continue to be a scientific priority. The potential implications for forest conservation are mind-boggling!

ADDITIONAL REFERENCES

Entangled Life: How Fungi Make Our Worlds, Change Our Minds & Shape Our Futures by Merlin Sheldrake

Mycelium Running: How Mushrooms Can Help Save the World by Paul Stamets

Wikipedia, "Mycorrhiza", https://en.wikipedia.org/wiki/Mycorrhiza

Mushroom Expert https://www.mushroomexpert.com/

National Library of Medicine https://pmc.ncbi.nlm.nih.gov/articles/PMC8856089/

Mycoquebec https://www.mycoquebec.org/liste-especes.php

Science Direct https://www.sciencedirect.com/

Studies in the Amanitaceae http://www.amanitaceae.org/?Home

5 Fungal endophytes as prolific source of phytochemicals and other bioactive natural products: A review. Microbial Pathogenesis; Volume 82, May 2015, pages 50-59

Pleasing fungus beetles (*Erotylidae*) are highly specialized fungus feeders, relying on fungi such as this **milkcap** (*Lactarius fragilis*) as a primary food source.

2. Fungi Benefiting Animals:
The Critical Role of Fungi in Wildlife Ecology

By Jerry Hassinger

Fungi are essential to ecosystems, influencing wildlife in ways that go beyond decomposition. They function as nutrient providers, ecosystem engineers, and population regulators, shaping biodiversity and helping to maintain dynamic ecosystems. Animals interact with fungi both directly—by consuming mushrooms—and indirectly, as fungi support plant growth through underground networks. While some fungi offer nourishment and shelter, others help regulate populations by acting as natural parasites.

This article explores how fungi benefit wild animals, with examples from mammals, birds, reptiles, amphibians, and invertebrates. For negative effects of fungi on wildlife, such as fungal parasites and pathogens, see article ***12. Regulators of Populations***.

Underground Food Webs: The “Hidden Kingdom”

In the Appalachian forest ecosystem, most mushrooms emerge between March and November, with some lasting from mere hours to weeks before they are consumed or decompose. However, the mycelial network beneath the surface—composed of fine, thread-like hyphae—exists year-round, earning fungi the nickname “the hidden kingdom.” Rich in nitrogen and phosphorus, this unseen fungal biomass is the foundation of many forest ecosystems, directly impacting plants and animals. It is critical for feeding microarthropods (80% of which are fungivores[1]), improving soil fertility by breaking down organic matter and releasing nutrients, and sequestering carbon through the proliferation of vast mycelial networks.

How Fungi Benefit Animals

Fungi benefit animals in three major ways:

1. As **symbiotic partners:** fungi enhance plant growth, indirectly benefiting herbivores and omnivores.
2. As **decomposers and nutrient recyclers**: fungi break down organic matter, enriching the soil and creating habitats.
3. As **population regulators**: parasitic fungi help control insect and plant populations, reducing ecosystem imbalances.

Over time, this fungal-based ecological triad (partners, decomposers, and parasites) promotes and benefits forest biodiversity. This relationship is not one-sided—fungi benefit animals, but animals also support fungi. Fungivores and omnivores contribute to fungal dispersal by consuming and excreting viable spores, helping to sustain fungal populations and, in turn, maintaining the health and stability of forest ecosystems.

Symbiotic Partners

Most forest plants depend on mycorrhizal fungi to enhance root function. These fungi increase water and nutrient uptake, exchange nutrients for plant carbohydrates, and stimulate plant growth, indirectly benefiting herbivores and omnivores.

By strengthening plant health and growth, these fungal networks indirectly support herbivores and omnivores that depend on vegetation for food and shelter, reinforcing the interconnectedness of forest ecosystems. In return, mycorrhizal fungi expand their subterranean networks, sometimes producing mushrooms (sporocarps) above ground or truffles underground—key food sources for wildlife ranging from mammals and birds to arthropods, nematodes and microbes.

Decomposers and Nutrient Recyclers

Fungi decompose wood and organic matter, unlocking nutrients that would otherwise remain trapped. They create food sources for insects, which attract birds, mammals, and amphibians. In aquatic ecosystems, microscopic leaf-decaying fungi form the base of the food chain—Dr. Barrie Overton notes that "without aquatic microfungi, there would be no fish at the top of the food chain or eagles." As fungi decompose dead wood, they form soft log habitats for small animals and support larger omnivores like bears that dig into the logs for insect larvae. For more information, see article ***3. Decomposers & Recyclers***.

Amanita mushrooms are ectomycorrhizal fungi, meaning they form symbiotic relationships with the roots of various trees such as pine, oak, fir, or spruce.

The **violet-toothed polypore** (*Trichaptum biforme*) is one of the most common decomposers in Pennsylvania, breaking down dead hardwood.

Honey mushrooms (*Armillaria* spp.) are aggressive parasites that kill trees by spreading through roots and invading wood with rhizomorphs, cord-like fungal structures.

An **eastern gray squirrel** (*Sciurus carolinensis*) enjoys a snack of *Russula* mushrooms. Fungi are an important food source not just for insects and deer, but for small mammals too.

A **northern flicker** (*Colaptes auratus*) uses a tree cavity that has been softened by fungal decay.

Parasitic Fungi as Population Regulators

While parasitic fungi can harm individual organisms, they also create deadwood that decomposers rely on; influence tree and understory diversity by selectively affecting weaker trees; and regulate insect populations, preventing destructive outbreaks. For example, over 1,000 known parasitic fungi species infect insects, keeping their populations in check (2). For more info, see article *12. Regulators of Populations*.

Mycophagy: Animals That Eat Fungi

Fungivory, or mycophagy, refers to the consumption of fungi by various organisms. A wide range of species, including birds, mammals, insects, reptiles, amphibians, gastropods, nematodes, bacteria, and even other fungi, obtain energy and nutrients from fungal sources. Some animals, known as fungivores, rely exclusively on fungi as their primary food source, while others incorporate fungi into an omnivorous diet.

Beyond Consumption: How Animals Eat and Live with Fungi

Fungal consumption occurs across a wide range of animal groups, including predatory insects and arachnids, mammals, birds, reptiles, amphibians, and microorganisms. Studies have examined how different species forage for fungi and the ecological roles fungi play as part of their diets.

For a more scientific analysis, several global reviews provide extensive documentation on mycophagy across various taxa:

Mammals

A wide variety of mammals (one source lists 508 species in 15 orders) consume fungi, ranging from small rodents to large herbivores and omnivores (3). Small mammals such as shrews, voles, and mice frequently forage on fungi, taking advantage of their abundance in forested habitats. Larger mammals, including white-tailed deer, bears, and flying squirrels, also incorporate fungi into their diets, benefiting from their rich nutrient content.

Birds

Many bird species interact with fungi in diverse ways, either by consuming them directly or using them as nesting materials. Studies document 54 species in 27 families that eat fungi, while 176 species in 37 families use fungal material (rhizomorphs) for nesting. Blue jays are among the species known to include fungi in their diet. Other birds, such as veeries, use fungal rhizomorphs—root-like structures of fungi—for nest construction. Additionally, northern flickers, a species of woodpecker, frequently nest in tree cavities that have been softened or hollowed out by fungal decay. In Pennsylvania alone, 35 species rely on fungi-associated tree cavities. These interactions highlight the important role fungi play not only as a food source but also in habitat formation and nest-building for various avian species (4).

Reptiles

Reptiles are perhaps less commonly associated with fungal consumption, but it seems to be widespread in reptiles (one source lists 42 species in 7 families) with box turtles being among the notable mycophagists (5).

Amphibians

Amphibians, such as frogs and salamanders, play a significant role in both consuming and dispersing fungi, often forming mutually beneficial relationships with certain fungal species. Larger, aged polypore fungi, particularly those growing on decaying wood, create microhabitats that support amphibian populations. For example, **hemlock varnish shelf** (*Ganoderma tsugae*) and **sulfur shelf** polypores (*Laetiporus* spp.), have been observed sheltering salamanders. These cases highlight fungi's role in creating moist, protected microhabitats that amphibians rely on for survival.

Invertebrates

Invertebrates have a particularly strong relationship with fungi, with thousands of recorded interactions across numerous species. Slugs, snails, ants, and beetles are among the most common invertebrate fungivores, feeding on various fungal structures, including mushrooms, spores, and mycelium. Many insects, such as certain beetle species, are highly specialized fungus feeders, relying on fungi as a primary food source.

Beyond consumption, fungi serve as breeding and sheltering sites for numerous invertebrates. Many mushroom species contain cracks, crevices, and folds, attracting insects to use them for temporary refuge or reproduction, with numerous species laying eggs inside mushrooms. These microhabitats, in turn, support insectivores like toads and shrews, forming a complex ecological web that connects fungi, invertebrates, and larger predators.

The Ecological Role of Mycophagy

Global reviews highlight fungi's importance in maintaining dynamic ecosystems. Mycophagy contributes to:

1. **Spore dispersal**, ensuring fungal reproduction and forest ecosystem stability.
2. **Nutrient cycling**, as fungi consumed by animals return to the soil through waste.
3. **Animal nutrition**, providing essential compounds that support diverse diets.
4. **Habitat formation**, where fungal structures contribute to shelter and nesting materials.

These interconnections emphasize that fungi are not only food sources but also critical components of ecosystem health.

Among the **sulfur tufts** (*Hypholoma fasciculare*) and damp decay, a toad finds shelter—a perfect example of how fungi create the moist, hidden microhabitats amphibians depend on to survive.

Pleasing fungus beetles (*Erotylidae*) rely on fungi like this **hemlock varnish shelf** (*Ganoderma tsugae*) as their primary food source.

A snail feeding on a *Russula* mushroom shows how fungi sustain countless invertebrates in forest ecosystems.

This **Allegheny woodrat** (*Neotoma magister*) nest contains stored food items, including at least one mushroom, showcasing the species' diverse foraging behavior.

Though the **northern flying squirrel** (*Glaucomys sabrinus*) feeds mostly on underground truffles, it won't pass up a snack of jelly fungi when it finds one.

Featured Species: Wildlife That Depend on Fungi

White-Tailed Deer (*Odocoileus virginianus*)

White-tailed deer incorporate fungi into their diet, with reports indicating they consume up to 580 different fungal species.

Allegheny Woodrat (*Neotoma magister*)

Listed as a threatened species in Pennsylvania, the **Allegheny woodrat** inhabits rocky outcrops and stores food for winter. Observations dating back to 1949 documented large fungal caches, including bushels of dried *Russula* mushrooms and puffballs. More recent studies by the Pennsylvania Game Commission recorded 1,097 midden sites, with mushrooms and lichens stored in 47 of these locations. Seasonal variations influence the availability and selection of fungi collected.

Northern Flying Squirrel (*Glaucomys sabrinus*)

The endangered **northern flying squirrel** in Pennsylvania depends heavily on fungi, with over 80% of its diet consisting of truffles—underground fungi that form symbiotic relationships with high-elevation hemlock and spruce trees. As truffles mature, their spores release strong scents that attract the squirrels, which dig them up and consume them. These spores remain intact through digestion and are excreted in new locations, facilitating truffle and tree growth. This relationship underscores the mutual dependence between the squirrel, truffle fungi, and the trees.

The Interdependence of Fungi & Wildlife

Fungi play a multifaceted role in supporting animal life, providing food, shelter, and ecosystem stability. Animals, in turn, contribute to fungal spore dispersal, decomposition, and biodiversity maintenance. Whether as a food source, decomposer, or habitat provider, fungi are an integral part of wildlife survival and ecosystem health. Recognizing and preserving these interactions is crucial for biodiversity conservation.

LITERATURE CITED

1. Moldenke, A.R. (1999). Soil-dwelling arthropods: their diversity and functional roles. In R.T. Meurisse, W.G. Ypsilantis, & C. Seybold (Eds.), Proceedings: Pacific Northwest Forest and Rangeland Soil Organism Symposium, Corvallis, Oregon, March 17-19, 1998 (pp. 33-44). General Technical Report PNW-GTR-461. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
2. Why death by parasite keeps life in the forest thriving | Live Science
3. Elliott T.F., Jusino M.A., Trappe J.M., Lepp H., Ballard G.-A., Bruhl J.J., Vernes K. A (2019) Global Review of the Ecological Significance of Symbiotic Associations between Birds and Fungi. Fungal Divers. 2019;98:161–194. doi: 10.1007/s13225-019-00436-3. [DOI] [Google Scholar]
4. Elliott TF, Truong C, Jackson S, Zúñiga CL, Trappe JM, Vernes K (2022). Mammalian mycophagy: a global review of ecosystem interactions between mammals and fungi. Fungal Systematics and Evolution 9: 99–159. DOI: https://doi.org/10.3114/fuse.2022.09.07
5. Elliott T. (2019) Reptilian Mycophagy: A Global Review of Mutually Beneficial Associations between Reptiles and Macrofungi. Mycosphere. 2019;10:776–797. doi: 10.5943/mycosphere/10/1/18. [DOI] [Google Scholar]
6. Santamaria B, Verbeken A, Haelewaters D. Mycophagy: A Global Review of Interactions between Invertebrates and Fungi. Journal of Fungi. 2023; 9(2):163. https://doi.org/10.3390/jof9020163

The **bitter oysterling** (*Panellus stipticus*) is a common decomposer of dead hardwoods in Pennsylvania. It grows in shelving clusters in the spring through fall, causing white rot and helping to recycle nutrients.

3. Decomposers and Recyclers: Powering the Cycle of Decay

By Jerry Hassinger

In every forest, decomposition is an essential process that recycles nutrients, creates habitats, and maintains dynamic ecosystems. Without decomposers, forests would be buried under layers of fallen leaves, dead trees, and organic debris, preventing new growth.

Fungi, along with bacteria and invertebrates, play a vital role in breaking down dead plant and animal matter, making nutrients available to living organisms. Among decomposers, fungi are unique—they are the only organisms capable of breaking down lignin, the tough structural component of wood. This ability makes fungi indispensable for nutrient cycling and the health of forest ecosystems.

Saprobes and Detritivores

Saprobes and detritivores are organisms that feed and grow on dead organisms like leaves, dead wood, or animal carcasses. Saprobes (also called saprophytes, saprotrophs, or decomposers) are organisms that break down dead organic matter externally by secreting enzymes. Some fungi belong to this group, as do certain bacteria. Detritivores are organisms that consume and digest decaying material internally. This group includes earthworms, ants, termites, millipedes, dung beetles, and vertebrate scavengers.

The litter layer and topsoil are a living and life-giving natural resource, with both groups contributing to the decomposition process. Saprobes release nutrients into the soil, while detritivores help fragment organic matter, making it easier

Known for its caps covered with pointy scales, *Pholiota squarrosoides* is a white rot fungus that decomposes both lignin and cellulose in dead hardwood. It is widely distributed in North America.

Phellinus is a genus of white rot fungi that decompose lignin and cellulose, breaking down tough structural components of wood. The perennial, shelf-like fruiting bodies have a tough, cork-like flesh.

Dyer's polypore (*Phaeolus* spp.) is a common brown rot fungus associated with conifers.

for fungi and bacteria to break it down. A healthy forest consists of two major categories of fungi—saprobes and plant partners (mycorrhizal fungi). While this article focuses on decomposers, these categories are not mutually exclusive—sometimes, plant partner fungi also possess enzymes that contribute to the decay process.

How Fungi Break Down Wood

While bacteria and other organisms aid in decomposition, fungi are the only organisms capable of breaking down lignin, the tough compound that gives wood its rigidity. Fungal enzymes digest this material, gradually softening and decomposing wood. As fungi consume dead wood, they release trapped nutrients, including water, carbon dioxide, nitrogen, phosphorus, and calcium. These nutrients enrich the soil, fertilizing plants naturally. Unlike cultivated crops that require fertilizers, forests depend on fungi to recycle essential minerals.

The Enzymatic Power of Fungi

The intricacies of fungal wood decay involve the release of powerful enzymes to break down wood, which creates cascading ecological effects. The enzymes soften dead wood, making it attractive to insects, which in turn attract and feed birds. The softer wood also allows cavity-excavating birds, like woodpeckers, and gnawing mammals to create nesting sites. Invertebrates, reptiles, and amphibians find shelter in and under decayed logs and in tree hollows. In Pennsylvania alone, 35 bird species and 20 mammal species depend on tree cavities formed by fungal decay for shelter. These structures can persist for decades, benefiting multiple generations of wildlife.[1]

White Rot vs. Brown Rot

Not all fungi break down wood the same way. Wood-decomposing fungi are generally classified into two main types based on their decay strategy: white rot and brown rot fungi.

White Rot Fungi

White rot fungi break down both cellulose and lignin, the two primary structural components of wood. Because lignin is responsible for the rigidity and dark coloration of wood, its decomposition by white rot fungi leaves behind a soft, pale, and spongy material. White rot fungi are much more

1 https://extension.psu.edu/dead-wood-for-wildlife

The **ochre-banded conk** (*Fomitopsis ochracea*) is a brown rot fungus that grows primarily in northern coniferous forests but is also found on hardwoods. It produces kidney-shaped conks. It is a perennial conk that becomes hoof-shaped over the years.

The **hairy bracket** (*Trametes hirsuta*) is an early fungal colonizer (also called pioneer fungi) that initiates the process of fungal decay succession, paving the way for late colonizers like *Fomitopsis* to take over in the final stages of decomposition.

common than brown rot fungi and include species from the *Trametes*, *Ganoderma*, or *Phellinus* genera as well as cultivated species like **shiitake** (*Lentinula edodes*) or **button mushrooms** (*Agaricus bisporus*).

Brown Rot Fungi

Brown rot fungi, on the other hand, primarily break down cellulose while leaving lignin intact, resulting in crumbly, brown decay. This process causes wood to shrink and fracture into cube-like chunks, a decay pattern known as cubical brown rot.

Brown rot fungi are more commonly associated with coniferous trees such as pine and spruce, making them particularly important in boreal and temperate forests. One notable example is the **ochre-banded conk** (*Fomitopsis ochracea*), a widespread polypore in northern coniferous forests and a key contributor to brown rot residues that enrich forest soils.

Understanding the distinction between white rot and brown rot fungi helps researchers categorize fungal species, analyze forest decomposition rates, and assess ecosystem health. These fungi influence tree succession, soil enrichment, and habitat formation, making them indispensable to the functioning and regeneration of forests worldwide.

Factors Influencing Fungal Decomposition

The diversity and activity of fungal decomposers in a given forest depend on several key factors:

- **Microclimate**: Temperature, humidity, and seasonal variation affect fungal growth and decomposition rates.
- **Tree and Plant Diversity**: Different fungi specialize in decomposing specific tree species, meaning diverse forests support a wider variety of decomposers.
- **Animal Diversity (Especially Detritivores)**: Insects, earthworms, and scavengers help break down wood, increasing fungal access to nutrients.
- **Physical Nature of Dead Wood**: The location, size, and species of fallen trees determine which fungi colonize them and how quickly decomposition occurs.
- **Site Disturbances**: Ground compaction, pollution, and habitat destruction can disrupt fungal networks and slow decomposition.

Another confounding variable is that some decay fungi are also parasitic. All of these variables interact to impact the extent and rate of wood decomposition, making fungi key elements of ecosystem function.

Ecological Benefits of Wood Decay Fungi

Wood decay fungi are essential to forest ecosystems, playing a central role in nutrient cycling, habitat formation, and species interactions. Their ability to break down dead material sustains plant and animal life and shapes our forests.

Supporting Plant Growth

By decomposing dead material, fungi return essential nutrients to the soil, allowing plants to thrive. This process fuels the entire food web, from microorganisms to large herbivores.

This yarn was dyed with *Umbilicaria* lichen, yielding rich, purple tones from nature's own color palette.

This artistic collage of crust and polypore fungi highlights both the visual beauty and ecological importance of these decomposers and showcases the diversity of species discussed in this chapter.

Creating Habitats for Wildlife

As fungi decompose wood, they soften it, forming cavities and sheltering spaces for a variety of species. These hollowed-out areas become critical habitats for many animals. See article ***2. Fungi Benefiting Animals***.

Interacting with Other Decomposers

Fungi work with bacteria, insects, and scavengers to ensure complete decomposition. Termites, ants, and beetles break wood down, boosting fungal access, while fungi soften wood, making it easier for detritivores to consume.

Why Wood Decay Fungi Matter

On his original web site at Messiah University, Dr. Gary Emberger listed some of the reasons wood decay fungi are important. These reasons, currently archived at mushroomexpert.com, have been revised and augmented as follows:

Ecological Importance

- **Primary recyclers of wood:** Without decay fungi, forests would accumulate vast amounts of dead wood, preventing nutrient cycling and new growth, and exacerbating wildfires.
- **Nutrient release:** These fungi break down wood, unlocking essential nutrients for plants and soil health.
- **White rot vs. brown rot:** Different species decompose cellulose or lignin at different rates. This helps inform fungal taxonomy as certain genera consist solely of white or brown rot fungi.

Economic and Industrial Impact

- **Forest management challenges:** Some species cause tree decay, requiring foresters to assess risks to trees, timber, and property.
- **Pharmaceutical and industrial potential:** Many species are studied for medicinal and biotechnological applications, including antibiotic and enzyme production.
- **Myco-medicinals:** Used in traditional and modern herbal medicine for immune support and anti-inflammatory properties.

Culinary and Artistic Value

- **Edible fungi:** Many wood decay fungi are sought after for culinary use, including species like **oyster mushrooms** (*Pleurotus* spp.) or **lion's mane** *(Hericium erinaceus)*.
- **Natural dyes:** Hobbyists use fungi like the **dyer's polypore** (*Phaeolus* spp.) to dye wool and fabrics, creating unique natural pigments.
- **Photography and art:** The intricate forms and colors of wood decay fungi such as **turkey tails** (*Trametes versicolor*) make them favorite subjects for nature photographers and artists.

Scientific and Educational Significance

- **Research subjects:** Their decomposition processes offer valuable study opportunities for students and scientists.
- **Foraging interest:** Wood decay fungi are a reliable find regardless of season or weather.

Wood decay fungi play vital ecological, economic, and cultural roles. Their impact goes beyond decomposition, shaping forest health, industry, research, and art.

Boreal beard lichen (*Usnea subfloridana*), is one of several beard lichens found throughout Pennsylvania in areas far from coal power plants and urban air pollution.

4. Lichens:
Fungal Symbioses That Shape Our Environment

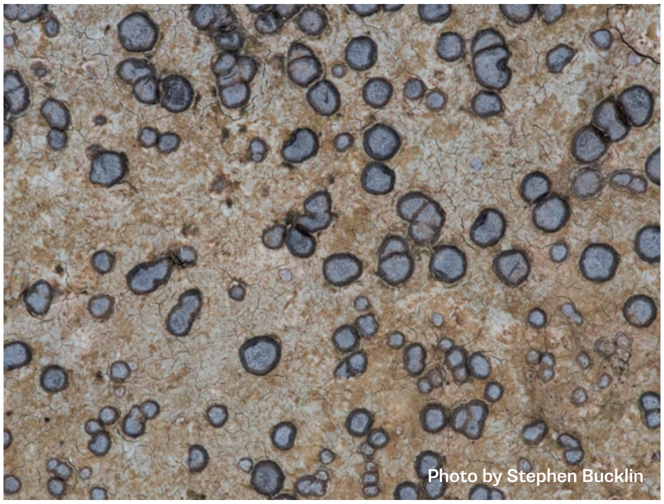
By Stephen Bucklin

What are lichens?

Lichens are a symbiotic association between fungi, algae and/or cyanobacteria, bacteria, and other microorganisms that form an integrated structure that allows all species involved in the partnership to thrive. While lichens are composite organisms, they are named according to the primary fungal partner and taxonomically classified as fungi. This is because the main fungus is the one consistent member of the symbiosis everywhere a given lichen is found, and because it is responsible for the overall appearance of the lichen. This association allows for fungi, which are typically only found in moist or humid environments, to live in extremely arid environments and other places that fungi struggle to survive in. Lichens come in a wide array of colors, shapes, and sizes, and grow on trees, rocks, soil, and almost anything else that stays still and undisturbed for a long time.

Most of the structure of a lichen is made up of fungal filaments from the single dominant fungal species. These filaments are differentiated into distinct layers and specialized structures that protect their photosynthetic partners from ultraviolet radiation and desiccation, manage moisture and humidity levels within and around the lichen, and allow for gas exchange, among other things. The existence of lichens challenges many of our beliefs and definitions—they turn the concepts of "species" and "individuals" on their heads. While one could think of lichens as fungi with specialized lifestyles, we are just beginning to understand how beautifully complex lichens are.

Examples of the three most common growth forms in lichens:



Crustose: Smokey-eyed boulder lichen *(Porpidia albocaerulescens)* is a common species on rocks.

Foliose: Powdery axil-bristle lichen *(Myelochroa aurulenta)* is a common species on tree bark and shaded rocks.

Fruticose: Dixie reindeer lichen *(Cladonia subtenuis)* is an infrequent species on soil.

Importance of Lichens in Pennsylvania

Lichens are everywhere, but their cryptic and slow-paced lives have led to them being largely overlooked or taken for granted. They play critical ecological roles, are biological indicators of air quality, and have cultural uses for medicine and natural dyes. Pennsylvania is home to at least 656 different species of lichens, many of which are endemic to the Appalachian and Great Lakes regions. Beyond these more tangible and quantifiable elements, lichens add an immeasurable beauty and charm to our landscape.

Ecological Connections

Lichens provide food and shelter to a variety of other species. In Pennsylvania, animals that consume lichens range from large mammals like elk and white-tailed deer, to small mammals like the Pennsylvania-endangered northern flying squirrel, to even smaller invertebrates like slugs, snails, and caterpillars. While lichens aren't a primary food source for our large mammal species, they are a reliable source of nutrition during the winter months when food is scarce. For invertebrates, the opposite is true—some species of moths rely largely on lichens as a food source in their larval stage.

Aside from using lichens as food, many invertebrates take shelter within lichens or use them as camouflage. This abundance of invertebrate life supports insectivorous bird species across the state, many of which also use lichens as nesting material. Over 50 bird species have been documented in North America constructing nests out of lichens or using them to camouflage the exterior or line the interior of their nests—potentially due to their unique secondary metabolite chemicals that reduce the presence of harmful bacteria, fungi, and parasitic invertebrates.

Indicator Species

Many species of lichens that were once abundant in Pennsylvania are now extirpated or rare, a story shared by much of the eastern United States where coal power plants, extensive logging, land conversion, and other industrial activities have severely impacted our landscapes and the biological communities that live there, including lichens. (See article ***9. Species of Special Conservation Concern***). Although lichens are resilient enough to survive in extreme environments like the Arctic and deserts, they are easily impacted by pollutants in our air.

The **painted lichen moth** (*Hypoprepia fucosa*), is one of several species of moths which feed primarily on lichens as larvae. Their bright colors serve as a warning to predators that they contain distasteful chemicals likely obtained from their lichen-based diet.

This **green leuconycta moth** (*Leuconycta diphteroides*), camouflages into a background of the **hammered shield lichen** *(Parmelia sulcata)*.

This **ruby-throated hummingbird** (*Archilochus colubris*) nest is constructed almost entirely of lichens held together with spider webs.

The **British soldier lichen** (*Cladonia cristatella*) is native to and widely distributed throughout Pennsylvania, making it a familiar sight in natural areas across the state.

Most lichens get all the nutrients they need from sunlight, precipitation, dew, and the dust particles that land on them. If these dust particles or rain contain sulfate ions (a byproduct of burning coal) or nitrates (a byproduct of many industrial activities such as driving cars and farming), many lichens will experience cellular damage and quickly decline.

Because of their sensitivity to certain air pollutants, lichens can tell us a lot about air quality over time. Most lichens that have a fruticose growth form—where the thallus organizes into a shrubby or hair-like structure that is three-dimensional—are considered sensitive to air pollution due to the increased surface area of these forms. These lichens cannot survive in areas with substantial pollution and their presence indicates cleaner air. Much of Pennsylvania has an industrial legacy associated with air pollution generated during the late 19th and early 20th centuries. Regions near industrial and urban centers were likely stripped of most lichen species and are beginning to recover thanks to legislation like the Clean Air Act and other environmental regulations. Despite these steps, some parts of the state are still heavily impacted by industry and vehicle emissions and the lichen communities present in places like Pittsburgh make this clear.

Lichens can also indicate the qualities of forest communities. Old growth forests can be defined as forest ecosystems that have remained intact for a long period of time without catastrophic changes. Because lichens grow slowly and have limited abilities to disperse and establish themselves in

Shaggy-fringe lichen *(Anaptychia palmulata)* is an example of an old growth indicator species found in Pennsylvania.

new environments, often older and more ancient habitats that have remained unchanged harbor greater lichen abundance and diversity. There are also unique microhabitats that form in old growth forests such as standing dead trees and large fallen logs, which can harbor specialized lichen species.

Cultural Significance

Lichens are masters of biochemistry. There are over one thousand unique chemical compounds known from lichens, hundreds of them found nowhere else in the natural world. Many of these secondary metabolite chemicals provide benefits to the lichen as protection from herbivores or ultraviolet radiation. Just as birds and other mammals have done, humans have discovered uses for lichens due to their unique chemical properties.

While lichens themselves are sometimes stunningly colored with shades of yellow, orange, red, green, and blue, they also contain hidden pigments that can be revealed and fixed to fibers to create vibrantly colored textiles. There are two historical instances where lichens became valuable sources of pigments that provided colors difficult to obtain from other natural sources, but in both cases the lichens that contained the desirable pigments became overharvested. In our modern world, we have synthetic pigments that have detached us from our reliance on natural sources of pigments, but there are still folks who collect and utilize lichens for this purpose. In Pennsylvania, the most responsible way to do this is to collect only from lichens that have fallen off their substrate (e.g., fallen branches), as these will soon decompose if not collected. Species of interest for this purpose include *Hypogymnia physodes, Punctelia rudecta,* and *Parmelia sulcata* which are all common and readily found on fallen branches after a storm.

Lichens have also been used for medicine by cultures around the world for centuries. The most common use of lichens in this way is the extraction of usnic acid, a powerful antibacterial compound. Usnic acid is also the chemical that gives many lichen species their distinctive bright yellowish-green color, as seen in species of *Usnea, Evernia, Ramalina, Flavoparmelia, Flavopunctelia, Xanthoparmelia,* and *Usnocetraria*. Lichen extracts from *Lobaria, Cetraria,* and *Usnea* species are also commonly used in natural cough or respiratory illness treatments. Many modern studies have investigated the potential anticancer, antioxidant, antiviral, and other benefits of lichens, and there are likely many uses yet to be discovered.

Lichens are incredible lifeforms that have many uses for humans and nonhumans alike. However, lichens grow slowly and in damaged and recovering ecosystems like those found throughout Pennsylvania, there are limited opportunities to sustainably harvest them. With time and a steadily increasing amount of care for how we treat our environment, especially our shared air, it is possible that many species of lichens formerly found in Pennsylvania may return and species that are rare or uncommon may become abundant.

Keep an eye on the PA Biological Survey's website for the release of a list of rare, threatened, and under-observed lichen species in need of further study. We'll be documenting these species using iNaturalist, where you can find the **Pennsylvania Bryophyte and Lichen Biodiversity Project**.

WORKS CITED

Allen, Jessica L, et al. Urban Lichens : A Field Guide for Northeastern North America : Including New York City, Chicago, Toronto, Boston, New Haven, Philadelphia, Baltimore, Washington, D.C. New Haven, Yale University Press, 2021.

Brodo, Irwin M, et al. Lichens of North America. New Haven, Yale University Press, 2001.

Hinds, James Wadsworth, and Patricia L Hinds. The Macrolichens of New England. The New York Botanical Garden Press, 2007.

Lücking, Robert, and Toby Spribille. The Lives of Lichens. Princeton University Press, 4 June 2024.

Sharnoff, Stephen. "Lichens of North America." Sharnoffphotos.com, 2025, www.sharnoffphotos.com/lichen_info/index.html. Accessed 14 Feb. 2025.

King boletes, also known as **porcini**, (*Boletus edulis*) are among the most sought-after edible mushrooms worldwide, including Pennsylvania. They are prized for their rich, nutty flavor and versatility in cuisines across Europe, Asia, and North America.

5. Food and Drink:
The Tradition and Benefits of Mycophagy

By David Wasilewski

The Tradition of Eating Wild Mushrooms

Collecting the fruit bodies of wild fungi for food—or for teas or tinctures believed to promote good health—dates back to ancient times. Before the arrival of European colonists, indigenous peoples in Pennsylvania may have consumed fungi. As one documented example of indigenous mycophagy, several northern tribes traditionally used *Phellinus igniarius* as a masticatory and smoking material in combination with plants and, later, tobacco. Long-standing traditions associated with many European and Asian cultures highlight the use of various types of fungi specific to those cultures.

As North America's population became more diverse with each wave of immigrants, the appreciation for wild fungi has followed suit. The popularity of certain edible mushrooms with Pennsylvanians stems from the influence of various European cultures, mainly during the 20th century; however, interest in using fungi as food has deeper historical roots in our state.

The first comprehensive field guide for North American mushrooms—*One Thousand American Fungi* published in 1900 by Philadelphians Charles McIlvaine and Robert K Macadam—places strong emphasis on the edibility, or inedibility, of various types of mushrooms they collected in Pennsylvania during the 1800s. More recently, the sharing of information via the internet has greatly increased both the general interest in foraging for wild mushrooms as well as the diversity of types of fungi deemed suitable for consumption.

Commonly foraged choice edible mushrooms in Pennsylvania

1. Morels (*Morchella* spp.) **2. Chanterelles** (*Cantharellus* spp.) **3. Hen of the Woods** *(Grifola frondosa)* **4. Black Trumpets** *(Craterellus fallax)* **5. Honey Mushrooms** (Popinkies) (*Armillaria* spp.) **6. Oyster Mushrooms** (*Pleurotus* spp.) **7. King Boletes** (Porcini) (*Boletus edulis* and allies) **8. Blewits** *(Collybia nuda)* **9. Chicken of the Woods** (*Laetiporus* spp.) Photos by Stephen Bucklin, David Wasilewski, and Barbora Batokova.

Wild Mushroom Hunting as a Form of Recreation

Pennsylvania is home to over 4.5 million acres of public forested land, offering abundant opportunities for mushroom foraging. Most state and local forests allow the gathering of modest quantities of wild mushrooms for personal use, but due to varying rules and regulations around mushroom picking between different types of state lands, it is best to contact the managers of your site of interest to ask how you're allowed to collect. Mushroom hunting in Pennsylvania has been steadily gaining popularity over the past two decades, with thriving mushroom clubs in western, central, and eastern PA. Outdoor recreation accounts for a significant portion of the state's economy, and interest in wild mushroom hunting is a relevant pillar of support. Moreover, the physical and emotional benefits people get from spending time in nature constitute an asset that is difficult to quantify. There is joy in finding a patch of chanterelles or morels. There is also the opportunity to learn about ecology. Mushroom hunting has served as the starting point for many careers in the biological sciences.

The Enjoyment of Cooking with Wild Mushrooms

Including wild mushrooms in food preparation is one aspect of the burgeoning interest in locally-sourced food. Many types of wild mushrooms are suitable as either comfort food side dishes or ingredients in recipes for high-end gourmet cuisine. Cooking with wild mushrooms is a gateway into an endlessly creative culinary endeavor.

Members of the Philadelphia Mycology Club at their first annual Fungadelphia Festival held on Sept. 7, 2024.

Members of the WPMC, including some members of the MYCO-TC, pose for a group picture before heading out into the woods at the Gary Lincoff Foray—a central activity to the club's mission.

Identifying Mushrooms

Identifying edible wild mushrooms requires more than relying on a few simple "shortcuts." Proper identification involves understanding key distinguishing traits and being able to accurately describe different species. To ensure safety and accuracy, anyone interested in foraging should join an established mushroom club and get at least three reliable field guides. Many local communities and clubs also have dedicated mushroom identification groups on Facebook, though these platforms may not provide reliable or expert-verified information.

Pennsylvania Mushroom Clubs

- Allegheny Woodrat Mushroomers
  facebook.com/AlleghenyWoodratMushroomers
- Central PA Mushroom Club
  centralpamushroomclub.org
- Eastern Penn Mushroomers
  epennmushroomers.org
- Johnstown Mushroom Club
  facebook.com/groups/1101680274302291/
- Ned Smith Center Mushroom Club
  nscmushroomclub.com
- Philadelphia Mycology Club
  phillymycoclub.com
- Western PA Mushroom Club
  wpamushroomclub.org
- Wyoming Valley Mushroom Club
  wvmclub.wixsite.com/wvmc

Recommended Field Guides for Pennsylvania

Field Guide to Wild Mushrooms of Pennsylvania and the Mid-Atlantic by Bill Russell

Mushrooms of Northeastern United States and Eastern Canada by Timothy J. Baroni

Mushrooms of the Northeast: A Simple Guide to Common Mushrooms by T. Marrone and W. Sturgeon

Mushrooms of Northeastern North America by Alan Bessette, Arleen R. Bessette, and David W. Fischer

100 Edible Mushrooms by Michael Kuo

Hunting Mushrooms: How to Safely Identify, Forage and Cook Wild Fungi by Barbora Batokova

Health Benefits Associated with Consumption of Wild Mushrooms

Beyond their culinary appeal, wild mushrooms have been recognized for potential health benefits. Over the past 50 years, scientific studies have explored the medicinal properties of various fungi.
The Cleveland Clinic lists seven such benefits:[1]

- Boosting the immune system
- Lowering blood pressure
- Providing a natural source of vitamin D
- Protecting brain health
- Supporting heart health
- Improving gut health

For example, a recent study has shown that **chanterelles** (*Cantharellus* spp.) are rich in vitamin D[2], while the **hen of the woods** *(Grifola frondosa)* is marketed for its health benefits. Any seasoned mushroom hunter will tell you that wild sheep's head mushrooms far surpass the cultivated kind—and finding one of these enormous, choice edibles is truly thrilling.

---

1 https://health.clevelandclinic.org/benefits-of-mushrooms
2 https://www.webmd.com/diet/health-benefits-chanterelle-mushrooms

Chaga (*Inonotus obliquus*)—the rugged, charcoal-like fungus growing on birch trees—has been valued for centuries as a medicinal mushroom and does occur in some parts of Pennsylvania.

The **scarlet caterpillar club** (*Cordyceps militaris*) is a striking parasitic fungus known for its traditional use in herbal medicine, often valued for its potential to support energy, immunity, and overall vitality.

While many enjoy **chicken of the woods** (*Laetiporus* spp.), some people experience gastrointestinal issues even when it's cooked thoroughly. It's best to try a small portion first to see if you tolerate it.

Medicinal Mushrooms and Traditional Uses

Beyond edible mushrooms, for some foragers, the pursuit of "medicinal" mushrooms is the goal. Many so-called "medicinal effects" originate from centuries-old folklore, though modern research has begun to validate their potential benefits. Some notable examples commonly found in PA:

- **Chaga** *(Inonotus obliquus)*
- **Reishi** (varnished *Ganoderma* spp.)
- **Scarlet caterpillar club** *(Cordyceps militaris)*

These fungi are not usually eaten. Instead, they are brewed into tea or extracted into tinctures, with just a few drops added to drinks. Also see article ***6. Medicine & Health Products.***

Concerns Associated with Collecting and Consuming Wild Mushrooms

As with any outdoor activity, there are risks associated with wild mushroom foraging for consumption. Proper identification, caution, and adherence to regulations are essential for both safety and sustainability.

Potential Health Risks

Not all edible mushrooms are well-tolerated by everyone. Some species that are generally considered edible may cause indigestion or other relatively minor unpleasant reactions for some people. Many species of fungi produce mushrooms that are considered inedible due to unpleasant taste, odor, or texture. The most significant danger comes from toxic and poisonous mushrooms, some of which are common in Pennsylvania. While some poisonous mushrooms cause temporary illness, others are potentially fatal. This underscores the importance of proper identification—never eat a mushroom unless certain of its identity.

Practicing Mindful Harvesting

There is little research to indicate the impact of mushroom harvesting on population health. Likely, impacts would be dependent on the particular species, location, and whether the population is weakened by other threats. Given their major biological and reproductive differences, fungi are not affected in the same way as plants. Impacts could also be different with commercial harvesting versus personal use harvesting or scientific collection. In Pennsylvania, commercial harvesting is prohibited on all state forests, parks, and game lands and the rules and regulations regarding personal use vary across these different state lands. Ultimately, regular monitoring of mushroom patches is a good practice to help observe if threats emerge.

Just like plants, fungi possess beneficial compounds and have a long history in folk medicine. Many species are now studied for their potential to support human health. While promising, more research is needed to understand their safety and effectiveness.

6. Medicine and Health Products:
Therapeutic Potential of Fungi

By Sarah L. Bashore

Historical Uses of Fungi in Medicine

The kingdom of Fungi, encompassing both mushrooms and molds, is a realm of mystery and magic. These organisms, often overlooked, play a crucial role in the delicate balance of our ecosystem and have profoundly impacted human history and culture. From the enchanting glow of bioluminescent mushrooms to the life-saving power of penicillin derived from mold, fungi have captivated our imaginations and shaped our world in countless ways. Mushrooms, the fruiting bodies of certain fungi, have long held a place in folklore and mythology. Their sudden appearance, often overnight, has led to tales of fairies, elves, and other mythical creatures. Some mushrooms possess psychoactive properties, leading to their use in spiritual ceremonies and rituals for centuries. The **fly agaric** (*Amanita muscaria)*, with its iconic red cap and white spots, is perhaps the most recognizable one, often linked to shamanic practices and even inspiring the imagery of Santa Claus in popular culture.

However, the world of mushrooms is not without its dangers. Many species are poisonous, and some are deadly. The **deathcap** mushroom *(Amanita phalloides)*, for instance, contains toxins that can cause irreversible liver damage and death. Foragers must possess a keen understanding of mushroom identification to avoid tragic consequences. Yet, even the most poisonous mushrooms have been used for medicinal purposes in traditional practices, highlighting the complex and often paradoxical relationship between humans and fungi.

The **fly agaric** *(Amanita muscaria)* features a striking red cap and white warts, making it one of the most recognizable mushrooms in the world. It is known for its psychoactive properties and used in spiritual rituals.

Penicillium chrysogenum is the fungal species responsible for producing the antibiotic penicillin, a groundbreaking medicine.

Penicillin: The Wonder Drug

Penicillin, a name synonymous with healing and a cornerstone of modern medicine, owes its existence to a fortunate accident and the keen observation of one man: Alexander Fleming. Its discovery revolutionized the treatment of bacterial infections and ushered in the age of antibiotics, forever changing the course of human history.

Prior to penicillin, bacterial infections were a leading cause of death. Simple cuts could become lethal, and diseases like pneumonia and sepsis were often untreatable. The world was plagued by illnesses we now consider easily curable. Into this landscape stepped Alexander Fleming, a Scottish bacteriologist at St. Mary's Hospital. While researching influenza in 1928, Fleming noticed something peculiar in a petri dish containing *Staphylococcus* bacteria. A mold, *Penicillium chrysogenum*, had contaminated the culture, and around the mold, the bacteria had failed to grow. This inhibition of bacterial growth was not a completely new phenomenon, but Fleming's brilliance lay in his recognition of its significance.

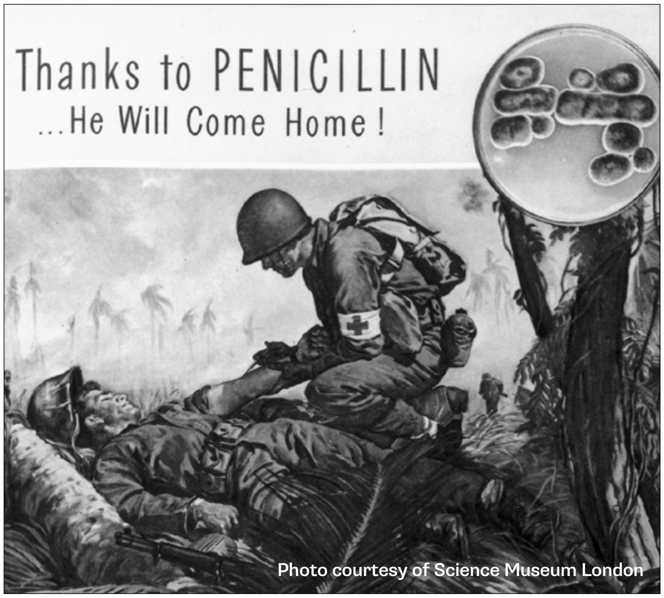
Fleming meticulously investigated the mold's properties. He discovered that the active substance it produced, which he later named penicillin, possessed potent antibacterial activity. It effectively inhibited the growth of a wide range of harmful bacteria in laboratory tests, publishing his findings in 1929 but without generating widespread interest.

The story of penicillin might have ended there, relegated to a footnote in scientific history, had it not been for the work of Howard Florey, Ernst Chain, and Norman Heatley at Oxford University in the late 1930s. This team, recognizing the potential of Fleming's discovery, revisited his research and developed a method to purify and concentrate penicillin in sufficient quantities for clinical trials. Their work, building on Fleming's initial observation, was crucial in transforming penicillin from a laboratory curiosity into a life-saving drug.

The first human trials of penicillin were conducted in 1941, and the results were nothing short of miraculous. Patients suffering from severe bacterial infections, previously facing almost certain death, made dramatic recoveries. The impact of penicillin was immediate and profound. During World War II, it played a critical role in saving the lives of countless soldiers wounded on the battlefield, significantly reducing mortality rates from infections.

The mass production of penicillin began soon after, driven by the urgent need for the drug during the war. The development of large-scale fermentation techniques allowed for the widespread availability of penicillin, making it accessible to both military personnel and civilians. This marked the beginning of the antibiotic era, transforming medicine and drastically improving human health outcomes.

Penicillin's legacy extends far beyond its immediate impact on treating bacterial infections.



Penicillin saved thousands of lives during the Second World War and is considered one of the contributing factors to the Allied victory. After the war, the drug became available to the public.

Ganoderma lucidum is often misapplied in North America. Local specimens are likely *Ganoderma curtisii* and *Ganoderma tsugae* while the true *G. lucidum* may appear in the wild as an escapee from cultivation.

It paved the way for the development of numerous other antibiotics, revolutionizing the treatment of infectious diseases. While antibiotic resistance is a growing concern, and the effectiveness of penicillin itself has diminished against some bacterial strains, its discovery remains a testament to the power of scientific curiosity and the importance of serendipitous discoveries.

Penicillin stands as a symbol of hope, a reminder of the potential for scientific breakthroughs to transform the world and alleviate human suffering. It is a story of accidental brilliance, collaborative effort, and the enduring power of a simple mold to change the course of medicine forever.

Treatment of Diseases with Biologically Active Compounds from Medicinal Fungi

Higher Basidiomycetes and Ascomycetes fungi possess various immunological and anticancer properties. They also offer important health benefits and exhibit a broad spectrum of pharmacological activities including antibacterial, antifungal, antiviral, cytotoxic, immunomodulating, anti-inflammatory, antioxidative, antiallergic, antidepressive, antihyperlipidemic, antidiabetic, digestive, hepatoprotective, neuroprotective, nephroprotective, osteoprotective, and hypotensive activities. The number of fungi on Earth is estimated at about 2–3 million species, yet more than 90% remain undescribed, with only around 130,000–150,000 formally named to date.[1] Fungi comprise a vast and yet largely untapped source of powerful new pharmaceutical products. In particular, and most importantly for modern medicine, they represent an unlimited source of polysaccharides with antitumor and immune-stimulating properties.

Fungal polysaccharides prevent oncogenesis, show direct antitumor activity against various allogeneic and syngeneic tumors, and prevent tumor metastasis. For example, a study published in the journal Nature in 2024 found that a compound derived from the mushroom *Ganoderma lucidum* was effective in killing cancer cells in vitro. Fungi are also being investigated for their potential to treat a variety of other diseases, including cancer, Alzheimer's disease, diabetes, and HIV/AIDS.

Cancer: A neoplastic disease caused by uncontrolled cell growth and spreading of those cells.

Metastasis: the spread of cancer cells from their original site (primary tumor) to other parts of the body.

Oncogenesis: process in which normal cells transform into cancer cells.

Antitumor: inhibits the growth of a tumor or tumors.

1 Niskanen, T., Thouvenot, L., Liimatainen, K., et al. (2023). Unveiling the global diversity, distribution, and conservation of fungi. Annual Review of Environment and Resources, 48, 22.1-22.32.

Gathered from birch trees, **chaga** *(Inonotus obliquus)* is valued for its medicinal properties and traditionally brewed as a tea or made into a double-extract tincture.

The shaggy **lion's mane** (*Hericium erinaceus*) may support cognitive function, nerve growth, and help combat neurodegenerative conditions like Alzheimer's.

Maitake (G*rifola frondosa*) is a culinary and medicinal mushroom known for immune support and blood sugar regulation.

Medicinal Mushrooms in Pennsylvania

Pennsylvania boasts a rich diversity of medicinal mushrooms, thanks to its varied ecosystems that range from deciduous forests to coniferous stands. Here are some notable examples.

Hemlock varnish shelf *(Ganoderma tsugae)*

This bracket fungus, often found on hemlock wood, is related to *Ganoderma lucidum* that has a long history of use in traditional Chinese medicine and that is known for its potential to boost the immune system, reduce stress, and improve sleep.

Chaga *(Inonotus obliquus)*

Primarily found on birches in colder climates, chaga is a powerful antioxidant and immune modulator. Often consumed as a tea, it is believed to have anti-cancer and anti-inflammatory properties.

Turkey Tail *(Trametes versicolor)*

This colorful mushroom, resembling a turkey's tail, is a common sight on decaying logs. It contains polysaccharides that may stimulate the immune system and have anti-tumor effects.

Lion's Mane *(Hericium erinaceus)*

This shaggy mushroom is known for its potential to support brain health and cognitive function. It may also promote nerve growth and have anti-inflammatory properties. Some studies have shown that lion's mane can improve memory and focus. For example, a study published in the journal Nutrients in 2023 found that lion's mane supplementation improved cognitive function in older adults with mild cognitive impairment.

Lion's mane is also being studied for its potential to treat Alzheimer's disease. A study published in the journal Phytotherapy Research in 2024 found that lion's mane supplementation improved cognitive function and reduced amyloid plaques in the brains of mice with Alzheimer's disease.

Maitake *(Grifola frondosa)*

Also known as hen of the woods, maitake is a delicious edible mushroom with immune-boosting and blood sugar-regulating properties.

Mushrooms and molds, the mysterious and magical members of the Fungi kingdom, have left an indelible mark on human history and culture. Their roles in folklore, medicine, ecology, and even cuisine are testaments to their profound influence. As we continue to unravel their secrets, we are sure to gain a deeper appreciation for these often-overlooked organisms and their vital contributions to the world around us.

Psilocybe ovoideocystidiata, commonly known as the **ovoid psychedelic mushroom**, is a naturally occurring species that contains the hallucinogenic compound psilocybin. It typically grows on woody debris. It was scientifically described from a type specimen collected in Pennsylvania.

Psilocybin-assisted therapy uses controlled doses of psilocybin to support treatment for mental health conditions such as depression, anxiety, and PTSD under professional supervision.

Psilocybin and PTSD

Post-traumatic stress disorder (PTSD) is a mental health condition that can develop after a person experiences or witnesses a traumatic event, such as war, assault, or a natural disaster. People with PTSD may have flashbacks or nightmares about the event, feel emotionally numb, or be constantly on edge. There is no cure for PTSD, but there are treatments that can help people manage their symptoms. These include psychotherapy, medication, and support groups.

In recent years, there has been growing interest in the potential therapeutic benefits of psilocybin for PTSD. Psilocybin is a psychoactive compound found in certain species of mushrooms. It has been shown to have a variety of effects on the brain, including reducing activity in the amygdala, the part of the brain that is involved in processing emotions.

Several small studies have shown that psilocybin-assisted therapy can be effective in reducing PTSD symptoms. In these studies, participants receive psilocybin in a controlled setting, along with psychotherapy. The psilocybin helps to create a state of mind in which people are more open to processing their traumatic experiences.

A study published in the journal JAMA Psychiatry in 2023 found that psilocybin-assisted therapy was effective in reducing PTSD symptoms in veterans. The study included 90 veterans with PTSD, who were randomly assigned to receive either psilocybin or a placebo. The results showed that the veterans who received psilocybin had a significant reduction in their PTSD symptoms, compared to the veterans who received the placebo.

While the results of these studies are promising, it is important to note that psilocybin is still a Schedule I drug in the United States. This means that it is illegal to possess or use psilocybin outside of a clinical trial.

There are also some potential risks associated with using psilocybin, such as the risk of experiencing a “bad trip.” A bad trip is a frightening or unpleasant experience that can occur when taking psilocybin.

If you are considering using psilocybin-assisted therapy for PTSD, it is important to talk to your doctor about the risks and benefits.

Mycoleather is a sustainable, mycelium-based alternative to animal leather, created by growing dense mats of fungal mycelium into durable, flexible sheets. It can be crafted into wallets, handbags, footwear, or upholstery, showcasing the potential of fungi in low-impact material design.

7. Mycoproducts: Driving Sustainable Innovation Beyond Food and Medicine

By Barbora Batokova

Fungi are often recognized primarily for their ecological, culinary, or medicinal value, but their significance extends far beyond that. The exciting world of mycoproducts, which encompasses a wide range of materials and applications derived from fungi, particularly mycelium, is rapidly evolving. From sustainable packaging to biodegradable textiles, mycoproducts seek to leverage the unique properties of fungi to help provide sustainable and innovative solutions to some of the most pressing environmental challenges we face today.

Biodegradable Materials

One of the most exciting applications of fungi is in the development of biodegradable materials. Traditional packaging and construction materials, such as plastic and Styrofoam (polystyrene), are expensive to produce and accumulate in landfills, significantly contributing to environmental pollution and waste. Polystyrene can take over 500 years to decompose, currently occupying about 30% of global landfill space.[1] Mycelium, the "root-like" structure of fungi, is being harnessed to create sustainable polystyrene alternatives from agricultural byproducts—an important step toward conserving resources and reducing reliance on fossil-fuel-based materials across industries.

Packaging

Mycelium packaging is biodegradable, allowing it to decompose within 30 to 90 days in moist conditions, thus returning nutrients back to the soil. It is also fast to produce, as it can be grown in custom molds in just 7 days.[2] The trailblazer in mycelium packaging is Ecovative, founded in 2007 and based in Troy, New York, which has developed both a rigid composite and a flexible foam, allowing companies like Ikea and Dell to become major early adopters. While the use of mycelium packaging is expanding, challenges remain in its scope of application, as it is primarily suited for protective packaging rather than versatile products like food containers. Despite these hurdles, increasing consumer demand for eco-friendly solutions may drive further innovations and investments in mycelium technology, enhancing its adoption across more sectors.

Construction

Mycelium products are emerging as innovative materials in the construction industry, offering sustainable alternatives to traditional building materials.

Mycelium can be used to create high-efficiency insulating panels. These panels are lightweight and provide thermal insulation, making them suitable for walls, roofs, and floors in energy-efficient buildings. Mycelium can also be molded into bricks that are not only biodegradable but also possess good fire resistance and acoustic properties. These bricks are lighter than traditional clay bricks and can be customized for various shapes and sizes. The Hy-Fi Tower, an installation at MoMA PS1 in New York showcased mycelium's potential in large-scale architectural applications.[3] Research is also exploring the potential of mycelium as a structural material. Projects like the MycoTree have demonstrated how mycelium can form the basis of a structural framework for buildings, showcasing its strength and versatility.

While these materials are gaining traction driven by the need for eco-friendly solutions, they are certainly not widespread in mainstream construction. Costs, regulatory approval, and large-scale production are still major hurdles.

Art and Design

Mycelium is being used as a medium for creating sustainable art. Mycelium can be cultivated to grow into various shapes and forms, allowing artists to create unique pieces that evolve over time. This blend of biology and art invites viewers to engage with the natural world in new ways and raises awareness about sustainability and ecological responsibility. For example, artist Abigail Brown

Ecovative's Mushroom Packaging is a planet-friendly protective packaging that combines agricultural feedstock with the natural binding strength of mycelium.

Developed by David Benjamin of The Living architecture lab, the Hy-Fi tower was built in 2014 from 10,000 low-energy, compostable mycelium bricks and exemplified innovation in sustainable architecture.

Abigail Brown's Living Sculpture project uses mycelium as a living medium, growing fungi on animal-shaped cardboard sculptures to explore themes of connection, decay, and renewal.


Photo courtesy of LLEV

Designed by Czech studio LLEV, these wine glasses were blown into mycelium molds made from *Ganoderma* sp. (center)—an innovative, sustainable glass-making method pioneered by the studio.


Photo courtesy of Deadwood

Reimagining fashion through the lens of biotechnology and sustainability, the Canoo Reishi Jacket is part of Deadwood's Mycelium Capsule, a collection made entirely in Fine Mycelium™ developed by MycoWorks.

developed the Living Sculpture project, where she created animal-shaped cardboard sculptures that serve as substrates for fungi to grow. The project explored themes of connection, decay, and renewal as mushrooms fruit from her sculptures. Brown's work emphasizes the transformative process of fungi, showcasing the dualities of life and death through art.

Mycelium is also used in furniture and decor, highlighting its value as both a sustainable material and aesthetic element. Designers are exploring its potential to create beautiful, functional pieces, such as desks, chairs, lamps, or bowls, that resonate with eco-conscious consumers while pushing the boundaries of traditional material use. For example, the LLEV design studio has revolutionized glass production by utilizing molds made from mycelium during the glass-making process. While the molds are composted after use, promoting a sustainable practice within the industry, the glassware is imprinted with the unique pattern of the mycelial network.

Pennsylvania's MycoFest, organized by MycoSymbiotics, is the largest mushroom and art festival in North America. Celebrating its 11th year in 2025, it brings together artists, scientists, and nature lovers for hands-on workshops in fungal art, cultivation, and sustainability. The festival promotes ecological literacy and creative collaboration rooted in the power of fungi.

In addition to sculpture and product design, artists are also incorporating mushrooms—as material or subject—into photography, collage, and mixed media, further extending their presence in the broader realms of visual and conceptual art.

Textiles and Fashion

The rise of fast fashion has led to an increase in resource consumption and waste. Mycotextiles, made from fungal mycelium, are sustainable alternatives to a wide range of traditional materials such as leather and silk, as well as synthetic fabrics. Brands like MycoWorks and Bolt Threads are at the forefront of this movement, creating new materials that are both durable and biodegradable.

For example, myco-leather offers a sustainable alternative to traditional leather, which often involves animal cruelty and significant environmental harm. Using minimal resources, myco-leather can be produced in a fraction of the time it takes to raise livestock for traditional leather. The production process results in fewer greenhouse gas emissions and reduced water usage.

Fungi can also produce natural dyes and pigments. The fashion industry has long been criticized for its reliance on synthetic dyes, which often contain harmful chemicals and contribute to water pollution. Fungal dyes provide a non-toxic, sustainable alternative that can impart vibrant colors to textiles while minimizing environmental harm.

Biofuels and Energy

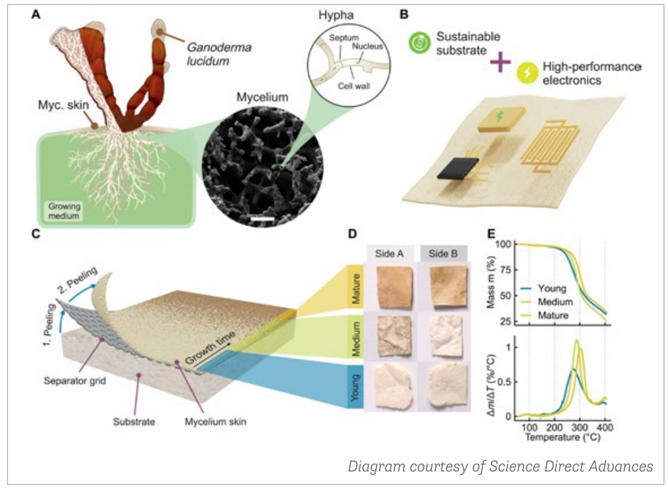
Fungi are also being explored for their potential in biofuel production. As the world seeks to transition from fossil fuels to renewable energy sources, bioethanol produced from plant biomass has emerged as a promising alternative that can power vehicles and machinery. Fungi can play a key role in this process by leveraging their unique biological capabilities to convert biomass into sustainable energy sources.

Research is also underway to develop mycelium-based batteries. For example, scientists in Austria have created "myceliotronics," which incorporate biodegradable mushrooms as a major component in electronics and batteries.[4] These biodegradable batteries could offer a more sustainable option for energy storage, reducing the environmental impact associated with traditional battery production and disposal.

Farming & Permaculture

Permaculture is a sustainable farming approach that works with natural ecosystems to create resilient, productive landscapes. Mushrooms play key roles by improving soil, recycling organic matter, and boosting efficiency. Saprophytic species break down materials like wood chips, straw, and cardboard into nutrient-rich compost, while also upcycling waste into food; their spent substrate serves as mulch or livestock feed. Mycorrhizal fungi form symbiotic relationships with plants, enhancing nutrient uptake and protecting against disease. Some fungi filter runoff and help remediate polluted soils. Their mycelial networks support plant health and resist pests, while extracts can serve as natural insecticides—making fungi vital to sustainable permaculture. For more, see articles ***10. Mycorestoration*** and ***11. Mycocontrol***.

These principles are being put into practice across Pennsylvania. Flannel Roots Farm, a micro permaculture farm in Belle Vernon, grows produce, mushrooms, and foraged goods using regenerative methods, blending farming with the arts to engage the community. Similarly, MycoSymbiotics—a permaculture and mycology collective in Harrisburg—advances food sovereignty, soil health, and resilience through education, consulting, and cultivation.



Mycelium grown from *Ganoderma lucidum* can be turned into biodegradable materials for sustainable electronics and energy storage.

Wine-cap stropharias *(Stropharia rugosoannulata)* are cultivated on wood chips, straw, cardboard, and other agricultural byproducts. This process transforms waste into nutrient-rich compost, improves soil structure and fertility, and produces delicious edible mushrooms.

Zone 3 in the concentric design zones in permaculture is ideal for low-maintenance mushroom cultivation—inoculate logs with spawn and let them quietly develop over a year before harvesting mushrooms.

REFERENCES

1. Davis, Joseph A. "Styrofoam Facts: Why You May Want to Bring Your Own Cup." Society of Environmental Journalists, SEJournal Online, vol. 4, no. 15, 2019, www.sej.org/publications/backgrounders/styrofoam-facts-why-you-may-want-bring-your-own-cup. Accessed 20 Jan. 2025.
2. "Mushroom Packaging by Ecovative." Mushroom Packaging, Mushroom Packaging, 2025, www.mushroompackaging.com. Accessed 20 Jan. 2025.
3. Caradonio, Jackie. "Hy-Fi: The Organic Mushroom Brick Tower Opens at MoMA's PS1 Courtyard." ArchDaily, 27 June 2014, www.archdaily.com/521266/hy-fi-the-organic-mushroom-brick-tower-opens-at-moma-s-ps1-courtyard. Accessed 20 Jan. 2025.
4. Li, Zhen, et al. "MycelioTronics: A Fungal Mycelium-Based Material for Sustainable Electronics." Science Advances, vol. 9, no. 1, 2023, doi:10.1126/sciadv.add7118. Accessed 20 Jan. 2025.

Photo by Barbora Batokova

Nearly all amanitas are mycorrhizal fungi that partner with plants to receive carbon directly from photosynthesis. By storing this carbon in their mycelium rather than releasing it through decomposition, they play a vital role in moving atmospheric carbon into the soil.

8. Sequestering Carbon: Fungal Importance to the Carbon Cycle and Our Climate

By Ella Serpell

Understanding the Carbon Cycle

To understand the importance of fungi as it relates to their power to sequester carbon, we first have to understand the importance of the carbon cycle—the process by which carbon moves between the atmosphere, land, and oceans. Carbon dioxide (CO_2) and other carbon compounds are absorbed from the air and incorporated into the earth through various biological processes before being released back into the atmosphere.

All living things are taking in some carbon into their bodies, and the very act of living also releases carbon constantly. Every time we eat and take on sugars, fats, and proteins, we are taking in carbon. Every time we breathe out, we are releasing a little bit of CO2. This is the most basic form of the carbon cycle.

Plants and other photosynthetic organisms are a very important part of this cycle, as they are the only organisms that can take carbon in the air and put it directly into their sugars or fats. This is part of why planting trees and healthy plant growth is good for the carbon cycle.

Processes that lock carbon away for a long time, often beyond the life of a single organism are very important. When carbon is locked away into the earth for a good length of time, this process is called carbon sequestration.

The Importance of Carbon Sequestration

This process is very important for keeping carbon stable on earth, and has contributed to keeping relatively predictable weather for most of human history. However, when this process is out of balance, it can cause fluctuation and more instability. Greenhouse gas emissions drive climate change by releasing large amounts of previously sequestered carbon from the earth into the atmosphere. The growing interest in enhancing carbon sequestration stems from its potential to counteract the effects of fossil fuel emissions and help restore carbon balance in the atmosphere. Though, it is worth noting that natural systems will never be able to keep up with the current rate of carbon emissions, hence carbon sequestration research must also be paired with efforts to reduce fossil fuel use.

Where is Carbon Stored?

Carbon sequestration occurs in both land and marine environments. Approximately 75% of carbon stored on land is stored inside of soil (1). Called soil organic carbon (SOC), this is the amount of carbon that remains locked underground rather than being released back into the air.

There are many ways that the carbon gets into the ground, and many forms that it can take. One of these forms is in the living (or dead) mass of hyphae that grow all throughout the soil. These are the mycelial threads of the fungal body, and though they are very thin and often hard to see, they can form dense nets and spread far throughout the soil, locking in lots of carbon as they do so. Thus, fungi play a crucial role in both sequestering carbon into the soil and releasing it back into the atmosphere. Maintaining a diverse range of fungi ensures that they can help complete all the necessary parts of the carbon cycle.

The Role of Fungi in Carbon Cycling

Fungi contribute to the carbon cycle in two ways. First, as decomposers that release carbon back into the atmosphere through the breakdown of organic material. Second, as mycelia that bring carbon underground. A particularly important type of fungi in sequestration are mycorrhizal fungi.


Photo by Barbora Batokova

A verdant wetland in the Beaver Meadows Area in Pennsylvania is a living carbon reservoir where water-logged soils and dense vegetation lock up carbon year after year.


Photo by Barbora Batokova

Delicate white mycelial threads spread through the soil, forming the hidden mycelial network. Though almost invisible, these networks lock in carbon and support ecosystems from the ground up.


Photo by Hannah Huber

This decaying log hosts a community of ascomycete fungi—*Chlorociboria*, *Ascocoryne*, and *Calycina* species—quietly breaking down wood.

Clavaria cf *amethystina* and *Clavulinopsis aurantiocinnabarina*—two vibrant decomposers—break down organic matter, releasing carbon back into the atmosphere while temporarily storing it in their fruiting bodies.

Microscopic view of arbuscular mycorrhizal fungi *(*Glomeromycota*)*, which form root symbioses that enhance nutrient exchange and help sequester carbon in soil.

Decomposers: Releasing Carbon Through Decay

Decomposers, or wood decay fungi, play an important role in releasing carbon out of the soil and into the atmosphere. Though decomposition releases carbon, it is a very important part of a natural ecosystem, and necessary for the nutrients available in a habitat. Interestingly, even as decomposers release carbon, their fungal hyphae still contribute to carbon sequestration by storing carbon within their own structures before eventual breakdown. To learn more about fungal decomposition, see article ***3. Decomposers & Recyclers***.

Mycorrhizal Fungi: Carbon Sequestration Underground

Though they sequester carbon in a similar way, through mycelium, mycorrhizal fungi sequester much more carbon than decomposers. This is because they do not get their carbon from decomposition, and thus release less carbon. By forming symbiotic relationships with plant roots, they exchange nutrients while obtaining carbon directly from their plant hosts. This means that the carbon they are storing has been freshly brought into the soil by the act of plant photosynthesis, making this type of fungi a very important channel for moving the carbon from the atmosphere into the soil.According to an estimate by Hawkins et al. (1), every year, 36% of the current annual fossil fuel emissions of the globe are carried by mycorrhizal fungi back below ground. While most of this carbon may be re-released, it shows the incredibly high impact these organisms have on the carbon cycle globally.

There are two types of mycorrhizal fungi that are most important for the carbon cycle.

Arbuscular Mycorrhizal Fungi: Supporting Carbon Storage Across Habitats

Arbuscular mycorrhizal fungi are soil microorganisms that form a symbiotic relationship with the roots of approximately 80% of land plant species (2). This makes them one of the most widespread, and they contribute to carbon storage across habitats. However, they are particularly important in wild habitats like grasslands, that are not dominated by the other kinds of mycorrhizae. They also associate with the majority of commercial crop species and are the fungi most often studied in agricultural science. However, because of fungicides and other conditions on intensively farmed lands, these fungi may not be present and active in the same way that they would be in a natural ecosystem. Trying to balance maintaining productive soils while also supporting soils becoming carbon sinks is going to require attention to the fungal community in the future (3).

Ectomycorrhizal Fungi: Carbon Storage in Forests

Ectomycorrhizal fungi associate with certain trees and woody plants, making them important in forests. Since over 60% of PA is forested, these are particularly important for our ecosystems and carbon storage (4). They grow around the outside of tree and shrub roots, forming dense underground networks that store large amounts of carbon while also producing charismatic edible mushrooms such as chanterelles, truffles, or king boletes. Though they have a limited habitat, they

The **common earthball** *(Scleroderma citrinum)* is mycorrhizal with hardwoods and conifers, and is often found in mossy areas or sometimes on well-rotted wood.

Widely distributed in North America east of the Great Plains, the **viscid violet cort** *(Cortinarius iodes)* is mycorrhizal with oaks and grows in the summer and fall.

are one of the most important types of mycorrhizal fungi for carbon sequestration. Ectomycorrhizal fungi receive more carbon from plants than other mycorrhizae, making them one of the most effective fungal groups for long-term carbon sequestration (1). However, not all "ectos" are created equal. For example, **earthballs** (*Scleroderma* spp.) may lock less carbon than **webcaps** (*Cortinarius* spp.), due to differences in their underground growth patterns.

Unfortunately, there is evidence that more polluted forests are less likely to support the types of mycorrhizae that sequester more carbon (5). This is a reminder that it is important not to just grow as many trees or forestry plantations as possible, but to foster and support healthy ecosystems.

Ectomycorrhizal fungi are also theorized to enhance the carbon sequestration through the Gadgil effect (5). Because ectomycorrhizal fungi are closely related to common decomposers, they compete for resources, slowing down the decomposition rate. The Gadgil effect suggests that when ectomycorrhizal fungi are abundant in a forest, they not only store carbon themselves but also reduce the activity of decomposers, slowing the release of CO_2. As a result, more carbon remains locked in the soil, increasing the forest's overall ability to sequester carbon.

Fungi's Impact on Carbon Balance and Climate Stability

A healthy carbon cycle requires a balance between carbon release and long-term storage. Fungi play an essential role in this process, acting as both decomposers that recycle carbon and mycorrhizal partners that store it underground. By enhancing carbon sequestration, fungi help mitigate climate change and make soil one of the most important carbon reservoirs on Earth. Maintaining healthy fungal communities is essential for sustaining carbon sinks, preserving ecosystem balance, and ensuring the long-term stability of Earth's climate.

SOURCES

1. Hawkins, H.J., Cargill, R.I., Van Nuland, M.E., Hagen, S.C., Field, K.J., Sheldrake, M., Soudzilovskaia, N.A. and Kiers, E.T., 2023. Mycorrhizal mycelium as a global carbon pool. Current Biology, 33(11), pp.R560-R573.
2. Arthur Schüßler, Daniel Schwarzott, Christopher Walker, A new fungal phylum, the Glomeromycota: phylogeny and evolution* *Dedicated to Manfred Kluge (Technische Universität Darmstadt) on the occasion of his retirement. Mycological Research, Volume 105, Issue 12, 2001, Pages 1413-1421, ISSN 0953-7562, https://doi.org/10.1017/S0953756201005196.
3. Hannula, S.E. and Morriën, E., 2022. Will fungi solve the carbon dilemma?. Geoderma, 413, p.115767.
4. "Forests and Trees". Commonwealth of Pennsylvania. https://www.pa.gov/agencies/dcnr/conservation/forests-and-tree.html
5. Suz, L.M., Bode, J., Byrne, A., Van der Linde, S. and Bidartondo, M.I., 2022. Nutrients, carbon, mycorrhizas and tipping points in forests.

With a conservation rank of S3, *Clavulinopsis appalachiensis*, or **Appalachian spindle coral**, is considered vulnerable. It is seemingly rare across the northeast region, but new populations have recently been discovered thanks to the spotlight of the FUNDIS Northeast Rare Fungi Challenge.

9. Species of Special Conservation Concern: Evaluating At-Risk Fungi

By Hannah Huber

The Biggest Threat to Fungi: Lack of Consideration

Fungi face many of the same threats as flora and fauna, namely habitat loss, climate change, invasive species (typically affecting symbiotic hosts), and pollution (Mueller et al., 2022), yet they are absent from most conservation frameworks. To address this, there is a movement underway to adopt the term “funga” into our vocabulary, so that like “flora and fauna,” there is at least a linguistic place and precedence for fungi in conservation frameworks (Kuhar et al., 2018). As of December 2024, over 1,000 scientists and 77 countries agreed to adopt this term. Despite this progress, fungi remain largely unrecognized in the United States’ Endangered Species Act, with only two federally listed lichenized species. Therefore, the responsibility falls to the states to fold fungi into conservation frameworks and legislation.

Undersampling and Rarity

As funga are relatively undersampled compared to flora and fauna, some species could easily become extirpated before their existence in a location is ever documented. Therefore, many fungi are of tentative conservation concern simply because they appear rare—whether that’s because they’re rarely documented or truly rare is to be determined via greater sampling efforts. Certain fungal species tend to be better documented than others, particularly those that are larger, more conspicuous, or more easily identified. Lichenized fungi are also more frequently recorded, as they persist visibly attached to the substrate, unlike many fungi that remain hidden until they produce fruitbodies.

Golden chanterelles (*Cantharellus* spp.) are among the most prized wild edible mushrooms. Foragers often find them in summer and early fall, growing in symbiosis with trees.

Prized in traditional medicine, the **caterpillar fungus** (*Ohiocordyceps sinensis*) is collected from alpine meadows where it parasitizes caterpillars. The practice is both culturally significant and economically vital, though it raises concerns about sustainability and overharvesting.

The sheer diversity of fungi also poses a challenge in assessing their conservation status. Pennsylvania is home to thousands of microfungi and macrofungi, with new species documented every year. On a global scale, 92-97% of estimated global fungal diversity remains undiscovered (Hawksworth and Lücking, 2017), making conclusive identification difficult even for experts. For these reasons, establishing a baseline inventory is a major priority of fungal conservation work.

Collection and Harvesting

A frequently asked question is whether mushroom harvesting poses a threat to fungi. The answer depends on species and context. For many fungi, the visible mushroom is just the reproductive structure, while the perennial organism (mycelium) is hidden within the substrate. In this context, mushroom picking could even aid spore dispersal, especially when mushrooms are collected into an open-weave basket.

Harvestable species are often the best documented and monitored. However, when a species is commercially valuable, has a restricted range, or is susceptible to other ecological threats, the risk of overharvesting impact may be higher than harvesting for personal consumption. This scenario of overharvesting combined with habitat loss is exemplified by the decline of the **caterpillar fungus** *(Ohiocordyceps sinensis)* from the Himalayas (Hopping et al. 2018). Globally demanded for its alleged medicinal properties and as a major source of income for harvesters, this species experienced significant population declines. Studies revealed that its decline was driven not only by overexploitation, but also climate change, which reduced the species' preferred habitat. Ironically, without the massive foraging interest and observations in the field, the reasons for this species' decline may have gone unnoticed. Most fungi are not good edibles, and therefore are unlikely to be at risk of overharvesting, but also don't have the benefit of the watchful eye that edible species command.

Assessing the Conservation Status of Fungal Species

There are two major organizations that publish fungal species conservation status assessments: the International Union for Conservation of Nature (IUCN), which produces the Red List, a global database of threatened species, and NatureServe, a nonprofit organization that coordinates between the 60+ natural heritage programs across North America, including the Pennsylvania Natural Heritage Program (PNHP).

IUCN Red List: Global Fungal Conservation Assessments

The IUCN Red List of Threatened Species was established in 1964 to evaluate species based on factors such as population trends, habitat loss, and ecological threats. Species are classified into nine categories, ranging from **Least Concern** (LC) to **Extinct** (EX), with **Critically Endangered** (CR), **Endangered** (EN), and **Vulnerable** (VU) collectively considered threatened species.

NatureServe Conservation Status Rankings

The NatureServe conservation status ranking system uses a numerical scale (1 = **Critically**

Turkey tail (*Trametes versicolor*) is a widespread and ecologically important fungus ranked G5/S5 by NatureServe methodology—meaning it is secure both globally and within many states. Its abundance contrasts with the rarity of many other fungal species.

DNA sequencing has revealed there are several distinct species of the jack-o'-lantern mushrooms—the **eastern American jack-o'-lantern** (*Omphalotus illudens*) being one of them, occurring in eastern North America and northern Europe.

Imperiled, 5 = **Secure**) and letter designations (X – **Presumed Extinct or Extirpated**, H – **Possibly Extinct or Extirpated**) applied at **global** (G), **national** (N), and **subnational** (S) levels to assess extinction risk in species and ecosystems. For example, **turkey tails** *(Trametes versicolor)* are a secure species, assigned to a G5 and S5 rank.

While NatureServe conducts global species status assessments (G-ranks), member natural heritage programs conduct subnational assessments (S-ranks). These rankings are informed by data on a species' range within the state, the area that is occupied by the species, population estimates, number of populations, any known threats, and any observed population trends.

Current Status of Fungal Conservation Assessments

As of 2025, fungal conservation assessments have made some progress:

- 1,302 species of fungi have been assessed using IUCN Red List criteria (iucnredlist.org), with over 520 classified as threatened and nearly 300 listed as data-deficient.
- Over 1900 species have had their global status assessed by NatureServe, with over 600 classified as threatened.
- At the state/provincial level, over 8,500 species have been assessed, with over 3,300 classified as threatened.

While these assessed species represent a small fraction of known fungal diversity (and a smaller fraction of estimated diversity), they provide a starting place for examining fungal threats and focusing conservation efforts.

Challenges in Fungal Conservation: Data Gaps & Genetic Verification

Fungal conservation faces significant challenges due to insufficient baseline data, difficulties in population tracking, and taxonomic uncertainty. Compared to plants and animals, fungi tend to be more under-documented, making it difficult to assess population trends and long-term threats.

Estimating fungal populations is further complicated by the fact that mushrooms can exist as clonal individuals or genetically separate individuals. Dahlberg and Mueller (2011) provide guidelines for distinguishing between the two based on fruiting pattern and substrate. Many of the 60+ natural heritage programs in the NatureServe network rank lichenized fungi, but tend to be further behind in assessing nonlichenized fungi such as mushrooms.

Additionally, genetic analysis has revealed that many fungi previously classified under the same name in Europe and North America are genetically distinct species. For example, the **jack o'lantern** mushroom *(Omphalotus olearius)* was once thought to be a single species worldwide, but DNA sequencing uncovered several distinct species across different ranges:

- *Omphalotus illudens:*
  Eastern North America and northern Europe
- *Omphalotus olivascens:*
  California
- *Omphalotus subilludens:*
  Southeastern North America
- *Omphalotus olearius*:
  Southern Europe

While the global species assessments from the IUCN Red List and NatureServe provide valuable insights, they should be approached with caution in the absence of conclusive genetic data from local specimens. Our local varieties may look the same on the surface as these globally-assessed species, but they may represent genetically distinct undescribed species with smaller populations that may be at an even higher risk of extirpation. Similar-looking species may still be related enough to have similarities in ecological needs, but we should take this information with a grain of porcini salt and be prepared for new information to challenge previously understood concepts.


Photo by Barbora Batokova

Blushers—*Amanita rubescens* in Europe and the *Amanita amerirubescens* species complex (pictured) in North America—are another example of genetically distinct species across different ranges. Currently, there are nine provisional species in the complex waiting to be named.

Species of Special Conservation Concern

Among the thousands of species of fungi documented in Pennsylvania, here are some examples that are priorities for promotion, inventory, monitoring, and continued assessment, based on their known threats, conspicuous appearance, regional rarity, or global assessment. For more species' statuses, consult the Pennsylvania Natural Heritage Program's website.

Ash Bolete (*Boletinellus merulioides*)

S-rank: **S2S3** (Imperiled to Vulnerable)

While most boletes are mycorrhizal, this easily identifiable species appears to be an "entomomutualist," forming a structure (sclerotium) underground that houses leafcurl ash aphids (*Prociphilus fraxinifolii*). It is theorized that the ash bolete feeds off the aphid's honeydew while the aphid feeds from the ash tree (Brundrett & Kendrick, 1987). As an ash tree symbiont, the future of ash boletes is uncertain due to the decline of ash from the emerald ash borer. To learn if this species could associate with other trees, we need ecological data, associated plant species, and lifecycle research.


Photo by Cara Coulter

While most boletes are mycorrhizal, the **ash bolete** (*Boletinellus merulioides*) appears to rely on a three-way relationship with ash trees and aphids, making its future uncertain as ash populations decline.

Harbinger-of-Spring Rust (*Puccinia erigeniae*)

S-Rank: **S2S3** (Imperiled to Vulnerable)

Harbinger-of-spring rust is an obligate parasite on the rare, early-blooming spring ephemeral plant harbinger-of-spring *(Erigenia bulbosa)*, which itself has a rank of S3 (vulnerable). It is legally listed as Threatened in Pennsylvania, but in 2021 the Vascular Plant Technical Committee recommended to the Department of Conservation and Natural Resources that the species' status be downgraded to Rare.


Photo by Stephen Bucklin

Harbinger-of-spring rust (*Puccinia erigeniae*) is a delicate parasite of the equally rare **harbinger-of-spring** (*Erigenia bulbosa*), and both face uncertain futures in Pennsylvania.

The Eight Species from the Northeast Rare Fungi Challenge Documented in Pennsylvania

1. Photo by Gregmarley – iNat #259897394 **2.** Photo by apacerva – iNat #123294513 **3.** Photo by Emma Richter - iNat #243667829 **4.** Photo by irene-w - iNat #65351967 **5.** Photo by rickclaypool - iNat #181182900 **6.** Photo by huafang - iNat #186365119 **7.** Photo by Jeff - iNat #183306499 **8.** Photo by Marcie Davis - The Bolete Filter.

Target Species of the Northeast Rare Fungi Challenge

The Challenge, created by the Fungal Diversity Survey (FUNDIS) in 2022, promotes the search and documentation of 20 charismatic, rarely observed species across the region from Quebec to Pennsylvania. Eight of these (listed below) have been documented in Pennsylvania, either recently or over a century ago.

Fibercap Strangler (*Squamanita umbonata*)

S-Rank: S1 (Critically Imperiled), possibly SH (Possibly State Extirpated)

A large, conspicuous species that was observed only once in Pennsylvania at Ohiopyle State Park in 1908, providing the holotype specimen from which the species was described.

Stalked Cauliflower Fungus (*Wynnea sparassoides*)

S-Rank: S1 (Critically Imperiled to Vulnerable)

This species was first documented from a rodent hole north of Pittsburgh during the 2004 Gary Lincoff Foray by the Western Pennsylvania Mushroom Club. In 2025, a second record was made when Paul Stanley, attending a Philadelphia Mycology Club walk at French Creek State Park, found a specimen dropped by a rodent from the canopy.

Yellowish-Green Entoloma (*Entoloma flavoviride*)

S-Rank: SU (Unrankable, Data Deficient).

Reported once in northeast Pennsylvania in 2016, this species belongs to the *Entoloma* genus, which includes many undescribed species. Given its small stature, it is likely under-documented, and DNA sequencing already suggests multiple lineages may exist. Genetic analysis is needed to confirm the 2016 specimen's identity.

Swamp Elfin Saddle (*Helvella palustris*)

SU (Unrankable, Data Deficient)

Mycologist Lee Oras Overholts collected a specimen from the vicinity of Stone Creek in Huntingdon and labeled it *Helvella palustris*, but close inspection and possibly DNA barcoding of the voucher is needed to verify its identity.

Billie's Bolete (*Boletus billieae*)

S-Rank: S1 (Critically Imperiled)

This species has been documented only once in Pennsylvania in 2016, in the southeast region by Luke Smithson.

Appalachian Spindle Coral
(***Clavulinopsis appalachiensis***)

S-Rank: S2S3 (Imperiled to Vulnerable)

Thirteen populations of this species have been recorded in Pennsylvania. Many of these populations were discovered in the 2020s, which is encouraging for this species' outlook.

Rooting Tube-Pore Polypore
(***Pseudofistulina radicata***)

S-Rank: S2 (Imperiled)

With nine populations recorded in Pennsylvania, this large, easily identifiable species is saprotrophic on oak and chestnut. Its rarity may be linked to the decline of American chestnut.

Peck's Bolete
(***Butyriboletus peckii***)

S-Rank: S1 (Critically Imperiled)

Four individuals have been observed in Pennsylvania, with records from 1931, 1945, and two unspecified dates. Given its presumed association with American chestnut, its scarcity may be due to the widespread decline of its host tree.

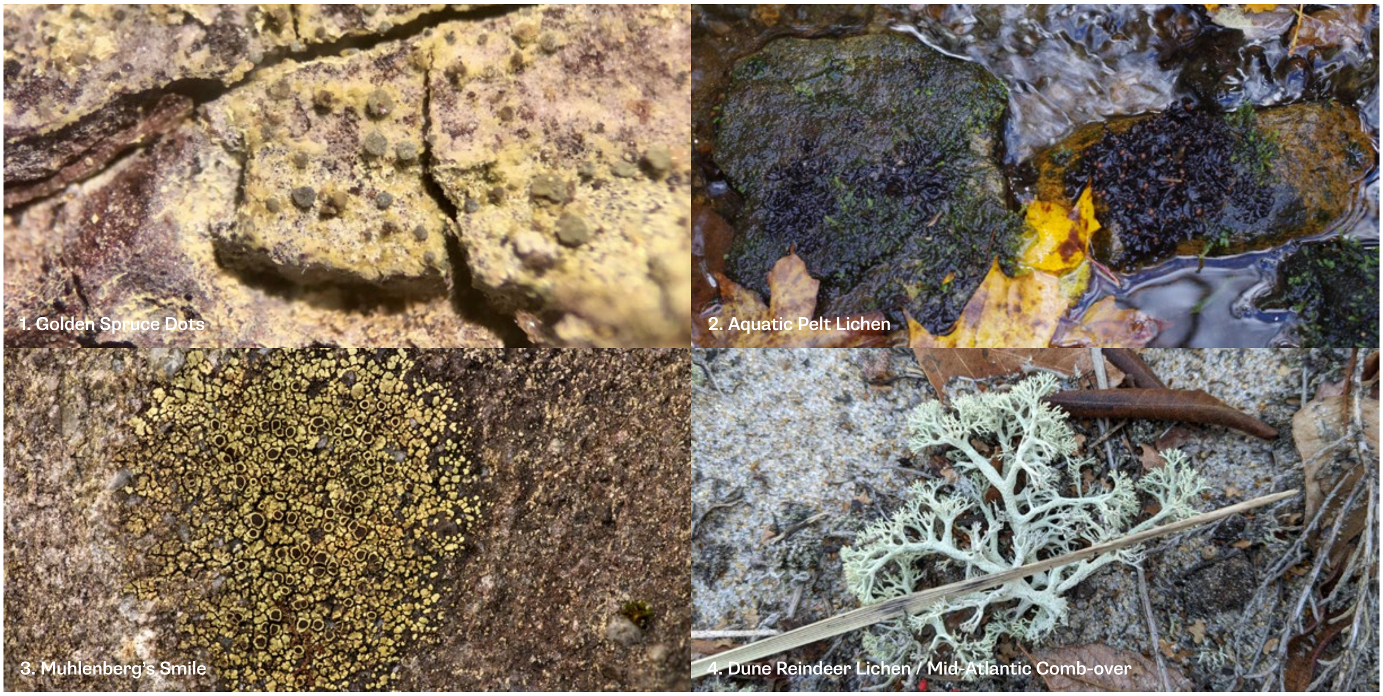
For these species, filling in data gaps entails taking good photographs, posting them to iNaturalist or Mushroom Observer, tagging the observation as the genus and species name (so that it shows up in the rare challenge projects), collecting and dehydrating a specimen and shipping it to the Fungal Diversity Survey lab in California. There is a team of volunteers who regularly scour iNaturalist and Mushroom Observer for observations of these species and coordinate with the observer to acquire the specimen and any further data needed.

Expanding Conservation Efforts Through Rare Fungi Challenges

The Northeast Rare Fungi Challenge followed the success of the West Coast Rare Fungi Challenge, with the Southeast Rare Fungi Challenge and Rocky Mountain Rare Fungi Challenge starting soon after. Each of these challenges has focused the efforts of mycology clubs and led to significant increases in distribution data and new state records for the target species. These species could serve as good starter batches for fungal assessments by natural heritage programs and as candidates for establishing regional rarity ranks.


Photo by Diana Baca

Lichens of Conservation Concern in PA



1. Golden Spruce Dots (*Arthonia cupressina*) – Photo by Tomás Curtis – iNat # 18018118 **2. Aquatic Pelt Lichen** (*Peltigera hydrothyria*) - Photo by Steve Messier - iNat #37233936 **3. Muhlenberg's Smile** (*Rinodina chrysomelaena*) - Photo by Jason Hollinger **4. Dune Reindeer Lichen / Mid-Atlantic Comb-over** (*Cladonia submitis*) - Photo Zac Peterson - iNat #105410618.

Don't Forget the Lichens

Lichens, which are symbiotic associations between fungi (mycobiont) and algae and/or cyanobacteria (photobiont), are also taxonomically classified as fungi and named according to the identity of the mycobiont. In Pennsylvania, the **tree lungwort** *(Lobaria pulmonaria)* is considered a "canary in the coal mine" species for lichen conservation due to its charismatic appearance and strong documentation history.

As of 2023, the species was determined to be extirpated from Ohio, highlighting the urgency of monitoring its status in Pennsylvania. One of the biggest threats to lichens is air pollution which tends to be a particular threat in the Midwest and western Pennsylvania (American Lung Association). Fortunately, the Environmental Protection Agency (EPA) under the Biden-Harris tightened air quality standards for emissions of fine particulate matter (PM 2.5) by 25%, which may benefit the 660+ species of lichenized fungi documented in Pennsylvania.

Many natural heritage programs have assessed more lichen species than mushrooms since lichens were often under the purview of botanists. Perhaps because lichens got more attention from botanists, they tend to be understudied in mycology club circles. Yet, lichenized fungi could serve as a gateway to broader interest in fungi within natural heritage programs. After all, as Canadian lichenologist Trevor Goward says, "lichens are fungi that have discovered agriculture."

Lichens of Conservation Concern in PA

Several lichen species in PA have been prioritized for state-level assessment and monitoring:

Golden Spruce Dots *(Arthonia cupressina)*

IUCN Endangered (2020) / NatureServe G2 (2024) / PNHP S1 (2025)

Aquatic Pelt Lichen *(Peltigera hydrothyria)*

IUCN Endangered (2023) / PNHP S1 (2025)

Muhlenberg's Smile *(Rinodina chrysomelaena)*

IUCN Critically Endangered (2015) / PNHP SH (2025)

Dune Reindeer Lichen / Mid-Atlantic Comb-over *(Cladonia submitis)*

IUCN Endangered (2021) / NatureServe G4 (2001) / PNHP S1 (2025)

Get Involved: Help Build Pennsylvania's Fungal Diversity Picture

The Pennsylvania Natural Heritage Program's fungi page will be a dynamic clearinghouse of information pertaining to fungi of concern, including posters featuring target species. Becoming familiar with rare species' general appearance can help you know what to report if you see something similar on your hikes. People are often surprised to learn that joining a mycology club can be a more effective way to learn field mycology than even a college course, due to the strength of the amateur community and dearth of employment for mycologists (in academia and in most other fields besides those focused on pathology). Having an iNaturalist or Mushroom Observer account will allow you to post pictures of the fungi you observe with GPS data. Getting a food dehydrator will allow you to dry specimens and mail specimens to DNA sequencing labs, reducing the guesswork in species identification and helping to reveal hidden species diversity.

For more information on the status of fungi of concern in Pennsylvania visit naturalheritage.dcnr.pa.gov/Fungi.html.

REFERENCES

American Lung Association. (2024). State of the Air 2024. Retrieved from https://www.lung.org/research/sota

Brundrett, M. C., & Kendrick, B. (1987). Short communication The Relationship Between the Ash Bolete (Boletinellus merulioides) and an Aphid Parasitic on Ash Tree Roots. Symbiosis.

Dahlberg, A., & Mueller, G. M. (2011). Applying IUCN red-listing criteria for assessing and reporting on the conservation status of fungal species. Fungal ecology, 4(2), 147-162.

Hawksworth, D. L., & Lücking, R. (2017). Fungal diversity revisited: 2.2 to 3.8 million species. Microbiology spectrum, 5(4), 10-1128.

Hopping, K. A., Chignell, S. M., & Lambin, E. F. (2018). The demise of caterpillar fungus in the Himalayan region due to climate change and overharvesting. Proceedings of the National Academy of Sciences of the United States of America, 115(45), 11489–11494. https://doi.org/10.1073/pnas.1811591115

Kuhar, F., Furci, G., Drechsler-Santos, E. R., & Pfister, D. H. (2018). Delimitation of Funga as a valid term for the diversity of fungal communities: the Fauna, Flora & Funga proposal (FF&F). IMA Fungus, 9(2), A71-A74.

Mueller, G. M., Cunha, K. M., May, T. W., Allen, J. L., Westrip, J. R. S., Canteiro, C., Costa-Rezende, D. H., Drechsler-Santos, E. R., Vasco-Palacios, A. M., Ainsworth, A. M., Alves-Silva, G., Bungartz, F., Chandler, A., Gonçalves, S. C., Krisai-Greilhuber, I., Iršėnaitė, R., Jordal, J. B., Kosmann, T., Lendemer, J., … Dahlberg, A. (2022). What Do the First 597 Global Fungal Red List Assessments Tell Us about the Threat Status of Fungi? Diversity, 14(9), 736. https://doi.org/10.3390/d14090736

Originally described from Pennsylvania, *Lasallia pensylvanica*, commonly known as the **Pennsylvania toadskin lichen**, is a rugged, leaf-like lichen with a warty texture that thrives on exposed rocks. Unlike the four endangered lichens profiled in this chapter, this lichen is widespread and common throughout the Central Appalachian region.

Trametes versicolor, commonly known as the **turkey tail**, is a white rot fungus with powerful enzymes that can break down complex pollutants. It has been used to clean up oil spills and remove heavy metals from contaminated soils, highlighting fungi's potential in environmental restoration.

10. Mycorestoration:
Using Fungi to Restore Degraded Environments

By Marion M. Kyde

Our environment faces unprecedented challenges from pollution, deforestation, and unsustainable land use practices. Innovative and eco-friendly solutions are emerging in response. Mycorestoration—using fungi to improve and restore degraded or polluted environments—offers a promising, low cost, eco-friendly, and effective alternative to traditional chemical and physical remediation efforts. There are four facets to the practice: mycoremediation, mycoforestry, mycofiltration, and the use of mycopesticides.

Environmental Challenges

Poor management of household, industrial, and agricultural waste adds insult to injury to our deteriorating environment. Pollution not only harms public health, food security, and biodiversity, it also undermines the global economy and restricts access to safe drinking water. More than 2 billion people have no access to safe water; over 22 million hectares of land are polluted. Flawed forestry management practices contribute to ecological degradation. Nearly ten million hectares of forest are deforested every year. Only a fraction of that loss is offset by replanting.

Limitations of Traditional Remediation Methods

Chemical and physical remediation methods are available to restore degraded environments, yet they are often expensive, time-consuming, produce poisonous byproducts, and are only moderately successful. Moreover, these techniques typically do not work on low concentrations of highly toxic chemicals.

Fungal Mycelium: A Promising Alternative

Fungal mycelium offers an innovative solution. It can break down a wide range of environmental pollutants including oil, pesticides, plastics, and animal waste. Fungi can also accumulate and sequester the toxic residues from wildfires which may contain arsenic, asbestos, chromium, lead and other harmful elements. White rot fungi in particular, including **turkey tail** (*Trametes versicolor*) and **oyster mushrooms** (*Pleurotus* spp.), are able to make numerous enzymes capable of digesting a variety of complex compounds, including organic pollutants. These fungi have been effectively used to break down the complex hydrocarbons in oil spills and to remove heavy metals—such as cadmium, copper, manganese, nickel, and lead—from contaminated soils (2). These and other saprophytic fungi can be trained to metabolize specific toxic substances, making them adaptable tools for targeted environmental cleanup efforts.

Mycoremediation

Mycoremediation uses fungal mycelium to break down chemical pollutants and bind toxic heavy metals in contaminated soil—a process for which fungi are remarkably effective. This process helps prevent harmful substances from leaching into the water supply and sequesters them for safe removal.

White rot fungi are able to degrade pesticides, insecticides, and herbicides into less harmful byproducts. Lindane, a neurotoxin banned in over 50 countries, can be converted to harmless chemicals in a mere month and a half by *Phanerochaete chrysosporium* (4) and *Pleurotus ostreatus* (5) in liquid culture. While these laboratory results are promising, field trials are needed to determine the effectiveness and scalability of such treatments under real-world agricultural conditions. White rot fungi have also been successfully employed to decompose the complex hydrocarbons found in oil spills.

Field studies—such as those following wildfires in California—have demonstrated the impressive capacity of saprophytic mushroom mycelium to remediate fire-damaged environments. Similarly, experiments designed to train fungi to digest plastic face masks and gloves have shown that these organisms can completely absorb and break down plastics within just a few weeks. While these results are promising, the current data remain limited. Further research is essential to validate and scale up this clean-up method for wider use.

White rot fungi like **oyster mushrooms** (*Pleurotus* spp.), make numerous enzymes capable of digesting a variety of organic pollutants.

Pyrophilous fungi like the **stalked bonfire cup** (*Geopyxis carbonaria)* have adapted to thrive in post-fire environments and have the ability to aggregate and stabilize burned soil through their mycelial networks, helping hold moisture and support seed germination.

The **indigo milk cap** (*Lactarius indigo*) is an edible mycorrhizal fungus used in mycoforestry to support tree growth, sequester carbon, and produce sustainable food within forest ecosystems.

Stropharia rugosoannulata, or **wine-cap stropharia**, is a promising species for mycofiltration—using fungal mycelium to filter and break down water contaminants, including harmful bacteria and chemicals.

Mycoforestry

The escalating demand for cropland is one of the primary drivers of global deforestation. Inoculating trees or forest plantations with beneficial fungi, particularly edible ectomycorrhizal species that form mutualistic associations with plant roots, may slow this demand. The practice not only enhances tree health and nutrient uptake, but also contributes to carbon sequestration and valuable sustainable food production, reducing the pressure to clear natural forest ecosystems for cropland. It is vital, however, to select species native to the region for inoculation of this kind.

Experimentation in Europe and New Zealand has been quite successful, albeit on a limited scale. (3) Most recent trials have used *Lactarius* species (e.g., *L. deliciosus*, *L. indigo*, and *L. subindigo*), while the **Perigord truffle** (*Tuber melanosporum*)—cultivated successfully for over fifty years—demonstrates that other edible mycorrhizal species might offer even greater benefits in terms of both nutritional yield and climate mitigation.

Additionally, mycoforestry can serve as an alternative to clearcutting and removal of woody debris. Inoculating such debris and leaving it in situ accelerates the decomposition process, returning valuable nutrients to the soil and preserving soil depth. While mycoforestry alone will not resolve the climate crisis, it represents an option with enormous potential as part of an integrated, sustainable land management strategy.

Mycofiltration

Mycofiltration employs fungi to filter and remove pathogens and contaminants from water sources. This process uses living fungal networks to trap and degrade harmful microorganisms and chemical residues. *Pleurotus* and *Stropharia* species are promising filtration candidates. Straw wattles inoculated with **wine-cap stropharia** (*Stropharia rugosoannulata*) were used as natural filters to reduce *E. coli* contamination in a 2016 study of wetland tributaries by students at the University of Washington Bothell. This technique can also be used to filter stormwater runoff—helping to intercept roadway residues of oil, gas, and rubber before they enter adjacent streams. However, further study is needed to perfect and scale up this method of water purification before it can deliver substantial economic and environmental benefits.

Mycopesticides

Mycopesticides offer an eco-friendly alternative to the chemical treatments commonly used to boost crop yields to feed growing populations. Conventional pesticides are often mutagenic, carcinogenic, and prone to accumulation in the environment, posing long-term risks to human health and ecosystems. Of course, the original mycopesticide comes from nature itself and probably cannot be improved upon. The **caterpillar fungus** (*Cordyceps militaris*) and allied species parasitize insects from within, destroying both their potential to inflict immediate damage to plants and to reproduce. This natural mechanism underscores the potential of mycopesticides as sustainable, self-regulating alternatives to synthetic chemical pesticides. See articles ***11. Mycocontrol*** and ***12. Regulators of Populations*** for more information.

OP CIT

1. Alexander, Renee 2019 The Counter.org
2. Adenipekun, CO, Lawal R (2012) Uses of mushrooms in bioremediation:a review. Biotechnol Mol Biol Rev 7:62-68
3. Thomas, Paul W. and Alistar S.Jump 2023 pubmed.ncbi.nim.nih.gov
4. Mougin, Christian, Claude Pericaud, Jacqueline Dubroca, and Marcel Asther 1997 Enhanced mineralization of lindane in soils supplemented with the white tor basidiomycete Phanerochaete chrysosporium . Soil Biology and Biochemistry Volume 29, Issues 9-10. September - October 1997, pages 1321-1324.\\
5. Rigas, Fotis, Konstantina Papadopoulou, Vicky Dritsa and K Marchant 2005. Bioremediation of soil polluted with lindane by Pleurotus ostreatus. Third European Bioremediation Conference. Chania, Crete, Greece

The *Beauveria bassiana* fungus, widely used as a biological insecticide to control a broad range of pest insects, is a naturally occurring entomopathogenic fungus found worldwide in soils. Above, it is shown growing on what appears to be a longhorn borer beetle.

11. Mycocontrol:
Harnessing Fungi to Manage Parasitic and Pathogenic Pests

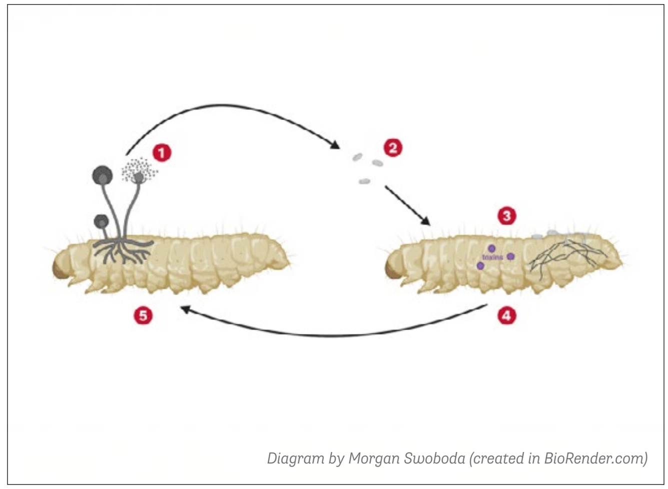
By Richard Jacob

Fungi cannot synthesize or make their own food, so like us they need to eat. We can split fungi into three rough groups based on how they obtain their nutrients. They can be saprotrophic, which means they eat dead organic matter. Or mycorrhizal and form a symbiotic relationship with the roots of a plant sharing food, water and minerals. Or they can be parasitic, which means they eat living organisms. Some fungi species can obtain their nutrients in two or even all three ways depending on their environment.

We mostly think of fungal parasites as bad when we notice them—they are attacking crops growing in the fields or as mold on produce in the grocery store or diseases on the plants in the garden. Or even worse, when they are attacking us and we have a fungal disease like athlete's foot.

There are many thousands of parasitic fungi, often with very specific hosts. Many are microscopic and we can only tell there is an infection by the physical damage to the host. There are plenty of fungal plant parasites in Pennsylvania. You might be familiar with powdery mildew or rust infections on your garden crops or if you live west of the Susquehanna River seeing majestic oaks dying from **oak wilt** (*Bretziella fagacearum*). Some insect-infecting species produce visible infections; the most known genus is the *Cordyceps* which infects insects and is known as the zombie fungus. Our Pennsylvania species are the **scarlet caterpillar club** (*Cordyceps militaris*) and *Cordyceps tenuipes*, both of which can be found across the state.

Chinch bugs damage rice by feeding on leaves and stems, causing browning and, in high numbers, killing young seedlings and reducing plant stands.



Infection process of entomopathogenic fungi. Spores and other fungal structures are enlarged to show detail and are not to scale with the host insect.

Mycoinsecticides

In the 19th century, while the transmissibility of diseases was being established, it was observed that insect diseases were infectious and contagious and that they could be transmitted from diseased to healthy individuals. The ideas were extended to using microbial and fungal parasites to manage insect pests. A lot of early work centered around the silkworm and the economically important industry of silk production. The soil fungus *Beauveria bassiana*, commonly known as the **icing sugar fungus** for the white powdery appearance it gives to infected insects, was first identified by Italian entomologist Agostino Bassi in 1835. By the 1880's researchers were experimenting with *Beauveria bassiana* to control the **chinch bug** (*Blissus leucopterus*), a major cereal crop pest. Although the initial experiments were of mixed success, they laid the groundwork for future work.

The research on fungi mycoinsecticides really picked up in the 1960's and with commercial products based on *Beauveria bassiana* coming to the market in that decade. There are now over 200 mycoinsecticide products available based on 9 different species of fungi. They are a popular alternative to synthetic pesticides as they are environmentally friendly and have lower research and development costs. The two species used in 80% of the products, *Beauveria bassiana* and *Metarhizium anisopliae*, are both naturally found in the soil. They target a wide range of pests across many insect orders, especially beetles, caterpillars, aphids, thrips, whiteflies, chinch bugs, plant bugs, stink bugs at both their larval and adult stages.

Mycoinsecticides work by spraying fungal spores or conidia, an asexual non-mobile spore, onto the plants, especially under the leaves. Insects come into contact with the spores which stick to their exoskeletons. The spores germinate and penetrate the insect, growing through the body and killing it in 3-14 days. The final stage is when the fungus fruits, breaking out of the insect's body and releasing new spores. However, the spores and their delivery methods are very inefficient—you need trillions of spores to treat an acre of greenhouse space effectively. The spores degrade quickly, and as far as current tests can determine, they do not cause any permanent environmental harm. Because mycoinsecticides only target a limited range of insects, crucially not bees, they are safe for humans and other animals. Also pests do not develop resistance to them which means they can still be effective after many decades of use.

The current market size for mycoinsecticides is estimated to be $550 million and they are ~10% of the biopesticides market. The worldwide use of microbial biopesticides is increasing as European legislation aims to reduce the amount of synthetic chemical pesticides used.

Mycoherbicides

Mycoherbicides were developed later than mycoinsecticides with early work starting at the beginning of the 20th century and the first product introduced to the USA market in 1995. Most of the mycoherbicides are based on *Colletotrichum* species that produce phytotoxins causing leaf and stem damage to the infected plants leading to death. Mycoherbicides have a very narrow range of action, normally just the one target species although some can target three or four.

Mycoherbicides work by spraying the spores or conidia of the fungus onto the leaves of all plants in a field or greenhouse. Under the right environmental conditions, humidity and temperature, the fungi will infect the plants causing leaf and stem damage and also allow other pathogens to enter the plants.

The bioherbicides market is estimated to be worth $3 billion worldwide but the mycoherbicide portion of that market is small, just a percent or two, less than $50 million.

The Future of Mycocontrol

Factors like stricter regulations on chemical pesticides, consumer demand for organic produce, and increasing awareness about environmental impacts are driving the growth of the mycocontrol market, but many challenges remain. They are not currently as effective as synthetic products and require optimal environmental conditions and delivery methods to work. They are most effective when used as a preventative measure rather than for treatment of an active infestation. On the other hand, insects and plants do not develop resistance to the products, so long-term use is assured. Research on improving delivery methods and new species or strains of species to use is expected to continue as the market expands in its use of mycocontrol products.

Colletotrichum species, which form the basis of most mycoherbicides, produce phytotoxins that damage leaves and stems, causing anthracnose, as shown here on black walnut leaves.

Consumer demand for organic produce and increasing awareness about environmental impacts are driving the growth of the mycocontrol market, but many challenges remain.

Corn smut disease, caused by the fungus *Mycosarcoma maydis*, occurs when fungal spores infect developing corn plants, especially during warm, wet, or humid conditions, forming grey, tumor-like galls on stems, leaves, ears, or tassels.

12. Regulators of Populations: Parasites and Pathogens of Plants, Animals, and Other Fungi

By Scott Stoleson

Some fungi live on or within other organisms and derive nutrients at the expense of that host (as parasites); some of these cause disease symptoms in, or even mortality of, their host (pathogens). The role of fungi as parasites and pathogens of other organisms is huge, but still poorly known relative to our understanding of bacterial and viral pathogens. Worldwide trends have shown that fungal emerging infectious diseases (EIDs) in both animals and plants are increasing through time as a proportion of disease alerts for all pathogens and are having a greater impact on host population sizes compared to other classes of pathogens.

Fungal pathogens infect a wide span of host organisms, from other fungi to plants and animals, including humans. Their effects on hosts can be minimal; for example, dermatophytic fungi such as *Trichophyton* spp., *Microsporum* spp., and *Epidermophyton* spp. cause the typically minor irritation of athlete's foot or ringworm in human beings. Other pathogenic fungi can have greater impacts on their hosts, including mortality. Often the virulence of fungal pathogens is greatest when inadvertently introduced by humans to host populations that have never evolved natural resilience.

Fungal Regulation of Plants

Crop-destroying fungal pathogens have long threatened humankind, causing innumerable famines throughout history. Currently, an estimated 10–23% of global crop yields are lost annually to fungal diseases. Since the 1950s, diseases caused by plant pathogens have been increasing in severity and scale, and today, emerging fungal diseases challenge global food supplies and human health.

Fungal Pathogens of Crops

Below are some of the many fungal pathogens of crop plants of regional or worldwide importance.

Black Knot (*Apiosporina morbosa*)

This species primarily affects plants in the genus *Prunus* like plums, cherries, apricots, or chokecherries. Without treatment, infected trees become stunted or die. In Pennsylvania, it can harm the quality of wild black cherry *(P. serotina)* timber and seed production.

Fusarium Wilt (*Fusarium oxysporum*)

This is a serious wilt disease that affects a wide range of grain and vegetable crops.

Rust Fungi

Many (about 4,000) leaf mycoparasites are classified as rusts due to their coloration. They tend to be specific to particular host species, of which many are important crops: *Puccinia graminis* is a common rust on wheat and *Phakopsora pachyrhizi* and *P. meibomiae* are common rusts on soybeans.

Rice Blast Fungus (*Magnaporthe grisea*)

This devastating ascomycete pathogen affects rice, substantially reducing rice yields worldwide.

Corn Smut (*Mycosarcoma maydis*)

This is a basidiomycete fungus with dual roles as a plant pathogen and a culinary delicacy. It causes corn smut disease in maize *(Zea mays)*, forming grey, tumor-like galls on stems, leaves, ears, or tassels. However, the young galls, known as huitlacoche, are prized in Latin American cuisine for their earthy, savory flavor.

Phytophthora

Although similar to fungi in appearance and confusingly called "water molds," *Phytophthora* species are not fungi and are evolutionarily distinct. This large genus of fungus-like organisms damages host plant tissues. The most infamous is *Phytophthora infestans*, causing the potato late blight responsible for the Irish Potato Famine in the 1840s.

Anthracnoses

Anthracnoses are a suite of leaf diseases of plants caused by a wide range of bacteria, viruses, but mostly fungi (e.g., genera include *Neonectria*, *Sirococcus, Discula, Fusarium,* and *Colletotrichum* among many others).

The **black knot** *(Apiosporina morbosa)* forms hard swollen black galls (tumor-like growths) on branches and occasionally on trunks of species in the genus *Prunus*.

Phakopsora pachyrhizi, a rust fungus on soybeans, is one of thousands of leaf-infecting mycoparasites. Rusts are often host-specific and include economically important species like *Puccinia graminis* on wheat.

The **rice blast fungus** (*Magnaporthe grisea*) is a destructive ascomycete pathogen that significantly reduces rice yields worldwide, posing a major threat to global food security.

American chestnut (*Castanea dentata*) was nearly wiped out by **chestnut blight** (*Cryphonectria parasitica*), but breeding and genetic engineering are helping restore resilient trees.

The **parasitic bolete** *(Pseudoboletus parasiticus)* is an obligate parasite of the **common earthball** *(Scleroderma citrinum)*. It grows in the summer and fall in Europe and North America east of the Great Plains.

Fungal Pathogens of Forest Trees

Our forests have suffered from numerous introduced fungal pests, resulting in losses of biodiversity and resources. Several keystone species of eastern North America have been especially hard-hit.

American Chestnut (*Castanea dentata*)
The once dominant tree of the Appalachians, American chestnut *(Castanea dentata)* has been decimated by the introduced chestnut blight *(Cryphonectria parasitica)* to the point where it has become ecologically extinct. Selective breeding and more recently, genetic engineering have made great strides in developing chestnut trees that genetically are almost pure *C. dentata* but exhibit resilience to the fungus.

American Elm (*Ulmus americana*)
Once widespread, the species has suffered severe die-off in much of its range due to Dutch elm disease fungus *(Ophiostoma novi-ulni)*.

American Beech (*Fagus grandifolia*)
This species has been slowly disappearing from eastern North America with the spread of beech bark disease complex, a fatal disease caused by the interaction of a non-native scale insect (*Cryptococcus fagisuga*) and two native fungi (*Neonectria faginata* and *N. ditissima*).

***Armillaria* spp.**
One of the most widespread and familiar of tree parasites is the honey mushroom complex, (*Armillaria* spp.), known to foresters and plant pathologists as Armillaria root rot. These fungi are considered secondary parasites because they do not infect healthy trees, but rather those already compromised by stress, physical damage, or other disease. They eventually kill their host but continue to feed off of it as saprobes; such blurring of lines between trophic roles tends to be common among fungi.

Fungal Regulation of Other Fungi

Numerous fungal species are classified as fungicolous: associated with other fungi species as either symbionts, saprotrophs, or as mycoparasites and hyperparasites. The latter groups can significantly alter population dynamics and sizes of host species, including commercially grown fungi for human food and medicine.

Mycoparasites occur in ecosystems from the poles to the tropics, in terrestrial and aquatic systems. As mycoparasites of pathogenic fungi, some fungicolous fungi have been explored as biocontrol agents: the secondary metabolites from fungicolous fungi are being researched for their potential as antifungal drugs and biocontrols. For more information see article ***11. Mycocontrol***. Below are some examples of mycoparasites in our region.

Parasitic Bolete (*Pseudoboletus parasiticus*)
Obligate parasite of the common earthball (*Scleroderma citrinum*), this macroscopic parasite can be easily observed because it appears above ground, protruding from its host, unlike the many species that are either microscopic or infect mycelia, sclerotia, or spores.

Hypomyces

The genus *Hypomyces* are all parasitic ascomycete fungi found throughout much of the world. They all live as parasites on other fungi in the form of a thin shell that grows over the host flesh, transforming the shape and color of the host's original appearance. Perhaps the most familiar to mycophagists is the lobster mushroom (*Hypomyces lactifluorum*), a parasite on Basidiomycetes in the family Russulaceae, that turns its host a bright orange with a granular texture.


Photo by Alan Rockefeller

The bright orange **lobster mushroom** *(Hypomyces lactifluorum)* is a parasitic fungus that colonizes species in the family Russulaceae, transforming their shape, texture, and flavor into a dense, seafood-scented edible prized by foragers and chefs.

Fungal Regulation of Invertebrates

Fungi infect a wide range of invertebrates and serve as important regulators of their populations. While the elevated body temperatures of higher vertebrates conveys some resistance to fungal infections, invertebrates lack this defense. Over 700 species of "entomopathogenic fungi" (insect fungal pathogens) have been identified, and this number is certainly a gross underestimate. These fungi have evolved a diversity of mechanisms to infect their invertebrate hosts and to maximize their reproductive potential.

Among the best-known and intriguing (horrific?) are various *Ophiocordyceps* species, some of which manipulate host behavior to expedite spore transmission. As one example, the tropical species *Ophiocordyceps unilateralis* (nicknamed "the zombie fungus") infects ants, slowly spreading and digesting the victim's body until it is ready to release spores, whereupon the fungus somehow hijacks the ant's behavior, making it crawl to the highest point nearby, latch on with its jaws, and die. A stalk grows out of the ant's head which releases the fungal spores into the air.


Photo by Denis Zabin

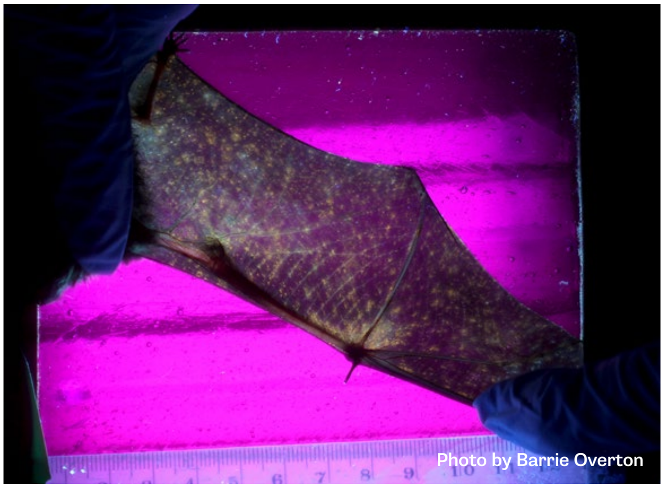
A parasitized ant grips to a branch, manipulated by the **zombie fungus** *Ophiocordyceps unilateralis*. The stalk emerging from its head contains the fungal spores that will be released to infect other ants below.

Managing spongy moth populations

Since the 1930s, Pennsylvania's oak forests have been hard hit by the introduced spongy moth (*Lymantria dispar*), resulting in severe economic and aesthetic losses due to tree mortality and defoliation. Expensive programs of spraying and the raising and release of parasites and predators mitigated damage to some extent. The situation changed radically with the appearance of the fungal pathogen *Entomophaga maimaiga*. Originally released as an experimental biocontrol for spongy moth in Massachusetts in 1910, it reappeared in northeastern states in 1989-1990 and rapidly became the dominant mortality agent for the moth.


Photo by Cara Coulter

Entomophaga maimaiga, a fungal pathogen, has become a key biocontrol for spongy moths (*Lymantria dispar*) in Pennsylvania, dramatically reducing defoliation and tree mortality in oak forests.



Under ultraviolet light, *Pseudogymnoascus destructans* appears along the wing of a bat. This cold-loving invasive fungus causes **white-nose syndrome**, infecting hibernating bats and devastating North American populations that lack natural resistance.

Amphibians infected with **chytridiomycosis**, caused by the fungus *Batrachochytrium dendrobatidis*, have damaged skin, disrupting the their ability to breathe and regulate electrolytes, often leading to death.

The fungus *Ophidiomyces ophiodiicola*, which causes **snake fungal disease**, can produce skin lesions, abnormal shedding, and cloudy or crusty eyelids, as seen on this infected snake.

Fungal Regulation of Non-Human Vertebrates

As mentioned above, fungi tend to be much less prevalent as pathogens or parasites of vertebrates due to endothermy of mammals and birds. However, some fungal diseases have had severe impacts.

Bat White-Nose Syndrome

Hibernating bats maintain a reduced body temperature; unfortunately, this creates a more hospitable internal environment for the fungal pathogen *Pseudogymnoascus destructans* (white-nose syndrome) to proliferate. This disease, inadvertently introduced to the Americas by cavers and spread primarily by bat-to-bat contact, has decimated bat populations in North America that have never evolved a natural resilience.

Chytridiomycosis in Amphibians

One of the most extreme cases of fungal impacts on vertebrate populations is the effect of the amphibian disease chytridiomycosis, caused by the chytrid fungus *Batrachochytrium dendrobatidis*. Amphibian populations across the globe have experienced catastrophic population declines and numerous extinctions in recent decades.

Snake Fungal Disease

Similarly, the snake fungal disease *Ophidiomyces ophiodiicola* has recently emerged across parts of the world, after being first discovered in New Hampshire. Its virulency varies with environmental conditions and snake species but tends not to be fatal. Long-term effects on longevity and reproductive effort remain unexplored, however.

Fungal Infections in Fish

Fish are susceptible to a host of diseases caused by various infectious agents including bacteria, viruses, protists, as well as fungi and fungi-like organisms (e.g., oomycetes). Fungal infections in fish generally are considered secondary to some other factor or pathogen, a consequence of water quality problems, poor condition, trauma, bacterial disease, or parasites. Most fungal pathogens of fish are in the phylum *Ascomycota* or are fungal-like oomycetes such as water molds (e.g., *Saprolegnia* spp).

Athlete's foot, also known as **tinea pedis**, is a common fungal infection by dermatophyte fungi (*Trichophyton* species), causing red, scaly, or blistered skin between the toes and sometimes affecting nails.

Ringworm is another common fungal infection caused by dermatophytes such as such as *Trichophyton*, *Microsporum*, and *Epidermophyton* species, producing circular, red, scaly, and itchy rashes.

Fungal Regulation of Human Beings

Many fungal pathogens affect humans, but relatively few are known to be serious threats compared to those caused by bacteria or viruses, in part because the normal body temperature of humans and other endothermic fauna are normally too high for most fungi to thrive. However, climate change is pushing some fungi to adapt over successive generations, expanding their ability to survive at higher temperatures—an emerging concern in health research. Consequently, some of the most frequently encountered fungal pathogens are external parasites, such as athlete's foot and ringworm.

Fungal infections within the human body tend to be less common but can be much more serious, especially for immunosuppressed individuals. Respiratory diseases caused by *Aspergillus*, *Cryptococcus*, *Coccidioides* and *Histoplasma*, among others, have increasingly been recognized as serious medical issues, particularly for those with weakened immune systems. *Candida* species, found commonly in the human gut and skin, are usually benign, but can cause discomfort if they spread to other areas, and life-threatening when they invade the bloodstream.

REFERENCES

American Academy of Microbiology. 2019. One Health: Fungal Pathogens of Humans, Animals, and Plants. Report on an American Academy of Microbiology Colloquium held in Washington, DC, on October 18, 2017. American Society for Microbiology, Washington DC.

Anderson PK, Cunningham AA, Patel NG, Morales FJ, Epstein PR, Daszak P. 2004. Emerging infectious diseases of plants: pathogen pollution, climate change and agrotechnology drivers. Trends Ecol Evol 19:535-544. http://dx.doi.org/10.1016/j.tree.2004.07.021

Bebber DP, Gurr SJ. 2015. Crop-destroying fungal and oomycete pathogens challenge food security. Fungal Genet Biol 74:62-64. http://dx. doi.org/10.1016/j.fgb.2014.10.012

Blehert DS, Hicks AC, Behr M, Meteyer CU, Berlowski-Zier BM, Buckles EL, Coleman JT, Darling SR, Gargas A, Niver R, Okoniewski JC, Rudd RJ, Stone WB. 2009. Bat white-nose syndrome: an emerging fungal pathogen? Science 323:227. http://dx.doi.org/10.1126/science.1163874

Blumenthal, E. M., & Wilt, R. G. (1998). Gypsy moth parasites vs. Entomophaga maimaiga in Pennsylvania. In Proceedings, US Department of Agriculture Interagency Gypsy Moth Research Forum, 1998: January 20-23, 1998. Gen. Tech. Rep. NE-248. US Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. https://doi.org/10.2737/NE-GTR-248

Brown GD, Denning DW, Levitz SM. 2012. Tackling human fungal infections. Science 336:647. http://dx.doi.org/10.1126/science.1222236

Cunningham AA, Daszak P, Wood JLN. 2017. One Health, emerging infectious diseases and wildlife: two decades of progress? Philos Trans R Soc Lond B Biol Sci 372:372. http://dx.doi. org/10.1098/rstb.2016.0167

Doehlemann, G., Ökmen, B., Zhu, W. and Sharon, A. (2017). Plant Pathogenic Fungi. In The Fungal Kingdom (eds J. Heitman, B.J. Howlett, P.W. Crous, E.H. Stukenbrock, T.Y. James and N.A.R. Gow). https://doi.org/10.1128/9781555819583.ch34

Fisher MC, Henk DA, Briggs CJ, Brownstein JS, Madoff LC, McCraw SL, Gurr SJ. 2012. Emerging fungal threats to animal, plant and ecosystem health. Nature 484:186-194. http://dx.doi. org/10.1038/nature10947

Humber, R.A. 2000. Fungal Pathogens and Parasites of Insects. In: Priest, F.G., Goodfellow, M. (eds) Applied Microbial Systematics. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-4020-1_8

Robert VA, Casadevall A. 2009. Vertebrate endothermy restricts most fungi as potential pathogens. J Infect Dis 200:1623-1626. http://dx.doi.org/10.1086/644642

Scheele BC, Pasmans F, Berger L, Skerratt LF, Martel A, Beukema W, Acevedo AA, Burrowes PA, Carvalho T, Catenazzi A, De La Riva I, Fisher MC, Flechas SV, Foster CN, Frías-Álvarez P, Garner TWJ, Gratwicke B, Guayasamin JM, Hirschfeld M, Kolby JE, Kosch TA, La Marca E, Lindenmayer DB, Lips KR, Longo AV, Maneyro R, McDonald CA, Mendelson J, III, Palacios-Rodriguez P, Parra-Olea G, Richards-Zawacki CL, Rödel M-O, Rovito SM, Soto-Azat C, Felipe Toledo L, Voyles J, Weldon C, Whitfield SM, Wilkinson M, Zamudio KR, Canessa S. 2019. Amphibian fungal panzootic causes catastrophic and ongoing loss of biodiversity. Science 363:1459-1463. DOI: 10.1126/science.aav0379

Stukenbrock, E. and Gurr, S. 2023. Address the growing urgency of fungal disease in crops. Nature 617, 31-34. https://doi.org/10.1038/d41586-023-01465-4

Vega FE, Goettel MS, Blackwell M, Chandler D, Jackson MA, Keller S, Koike M, Maniania NK, Monzon A, Ownley BH, Pell JK, Rangel DEN, Roy HE. 2009. Fungal entomopathogens: new insights on their ecology. Fungal Ecol 2:149-159. http://dx.doi.org/10.1016/j.funeco.2009.05.001

The **golden oyster mushroom** *(Pleurotus citrinopileatus)* is a striking, fast-growing edible species native to eastern Asia. Though cultivated for food, it has escaped into the wild in parts of North America, where its potential impact on native fungal communities is a subject of ongoing study.

13. Nonnative, Introduced, and Invasive Fungi: Understanding Their Ecological Impact

By Hannah Huber

Distinguishing Harmful Invasives from Native "Pest" Fungi

Another area of mycology where the lack of baseline inventory data is painfully evident is in distinguishing fungi as native versus non-native or introduced. There are many species that are non-native but don't cause apparent harm. It is when a species shows invasive behavior that the distinction becomes important. According to the United States Executive Order 13112 (1999), an invasive species is a species that didn't exist in an ecosystem until it was introduced there whether intentionally or unintentionally via human activity and that causes harm economically, environmentally, or to human health. It is equally important to recognize that while a native fungal pathogen may be considered a "pest," it should not be conflated as an invasive species. Native pathogens and parasites are regular members of many healthy ecosystems.

When a native pathogen becomes suddenly more aggressive, it may be the result of other ecosystem disturbances—such as climate change testing and expanding a species' growth parameters—compared to an invasive species' aggressiveness usually being due to the absence of coevolved species' regulation. For example, **cherry leaf spot** (*Blumeriella jaapii*) is a pathogen native to Pennsylvania that affects **cherry trees** (*Prunus* spp.). Cherry is an economically valuable tree, so declines are met with concern. Royo et al. (2021) suggested that before the passage of the Clean Air Act, cherry trees flourished from the increased nitrogen deposition, and hypothesized that a high relative abundance of black cherry would support a proliferation of associated pathogens. Therefore, in some cases, management of abundance, or creating gaps to reduce pathogen spread, may be an alternative to chemical treatment of native pathogens.

Positive Discoveries from Studying "Bad" Fungi

Sometimes, pathogenic fungi are the heroes and help combat invasive species of other taxa. For instance, *Ophiocordyceps delicatula*, is a fungus new to science that was discovered in Pennsylvania when it was infecting the invasive **spotted lanternfly** (*Lycorma delicatula*). Several other fungal species also take a bite out of the spotted lanternfly problem: *Batkoa major, Beauveria bassiana*, and *Metarhizium pemphigi* (Clifton et al., 2021), and researchers in Pennsylvania found fungi growing on egg masses that reduced hatching success (Taratut et al., 2025). This work was partly funded by the Western Pennsylvania Mushroom Club.

Similarly, studying invasive fungi can deepen our understanding of native species. Dr. Barrie Overton at Commonwealth University-Lock Haven has conducted intensive study of *Pseudogymnoascus destructans*, the introduced, invasive fungus implicated in causing white nose syndrome in bats. Through this work, Dr. Overton and his students have also discovered numerous presumably native *Pseudogymnoascus* spp. fungi that don't appear to cause disease in bats.

Mushrooms Can Be Invasive

Aside from pathogens and parasites, mycorrhizal fungi and decomposer fungi also can be introduced and invasive. The Pennsylvania Governor's Invasive Species Council maintains a list of all species considered invasive in the state. Invasive fungi are not listed separately but are mixed with plant and aquatic animal pathogens. Invasive mushrooms (fungi that produce a mushroom reproductive structure) are barely on the radar. With about 1,300 species of plants introduced to Pennsylvania, it is likely some symbiotic fungal associates were introduced along with them but remain undocumented. While many introduced fungi are recognized by regulatory agencies and pathologists, some mushroom-producing species—such as the **golden oyster mushroom**, the **deathcap**, and the **Asian beauty** fungus—may threaten native fungal biodiversity. As of this writing, my colleagues and I are working on a proposal to the Council for a fungi-exclusive list that includes both saprotrophic and mycorrhizal species.


Photo by grinnin (iNaturalist)

Cherry leaf spot (*Blumeriella jaapii*) causes spotting on cherry tree leaves (*Prunus* spp.). Its increased aggressiveness may be linked to an overabundance of black cherry trees and/or ecosystem changes like climate shifts, rather than invasive species dynamics.

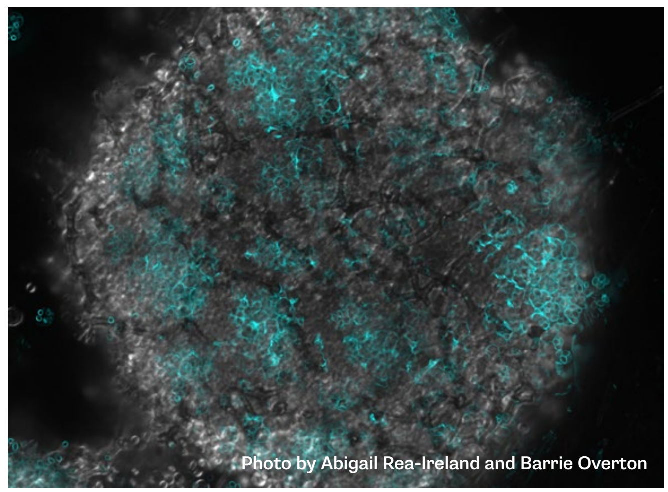


Photo by Abigail Rea-Ireland and Barrie Overton

The first published photo of the gymnothecium—a loosely woven, spore-bearing structure—showing the ascospores of a *Pseudogymnoascus* species. Until now, line drawings were the primary visual reference for this fungus' micromorphology.


Photo by John Plischke

A representative of the genus *Metarhizium*, this photo of *M. anisopliae* illustrates the appearance of entomopathogenic fungi like *M. pemphigi*, which infect and kill insects, including the invasive spotted lanternfly.

The **deathcap** (*Amanita phalloides*), a deadly poisonous mushroom native to Europe, is now mostly limited to parks and plantations in the eastern US and hasn't yet spread widely from initial introduction sites.

The **deathcap** (*Amanita phalloides*) has a smooth olive-green to yellowish cap, white gills, and a stem with a bulbous base and a volva. Its similarity to some popular edible mushrooms has lead to deadly poisonings.

Introduced Mushrooms to Know

Deathcap (*Amanita phalloides*)

The **deathcap** mushroom (*Amanita phalloides*) is a mycorrhizal species native to Europe that is, as the name suggests, deadly if ingested. Its introduced status has been studied on the west coast by mycologist Anne Pringle and others in a 2009 study with the earliest confirmed specimens having been collected in 1938 and 1945 from areas known to have imported plants—the grounds of a hotel and the University of California-Berkeley campus. DNA analysis of fruiting bodies collected between California and Europe, both by the study authors and from fungarium collections, showed decreased genetic diversity in California, suggesting the Californian populations stemmed from a few founding individuals.

The mushroom has also been found in undisturbed environments, including the Point Reyes National Seashore, and appears to grow with a California-endemic tree species, the **coast live oak** (*Quercus agrifolia*). David Aurora reported in his field guide ***Mushrooms Demystified*** (1979) that *Amanita phalloides* is the most common *Amanita* seen growing in the live oak woodlands. On average, the species is spreading over 3 miles per year, and nearly 6 miles per year in some areas of California. In a subsequent study, *Amanita phalloides* was found to dominate above ground mushroom biomass, and was frequently found growing on tree root tips (Wolfe et al., 2010).

In contrast to the California populations of *Amanita phalloides*, in the eastern US, as of a 2009 study, Pringle and Wolfe's team observed that the mushroom was more limited to parks and plantations in the eastern US, suggesting that at that time it hadn't yet started "invading" from the areas where it may have been introduced directly. Today, we still don't see an explosion of observations on iNaturalist, but the mushroom does have some lookalikes and its poisonous nature may lead it to be underdocumented. Wolfe's paper suggested that California's climate may be more conducive to the spread of the deathcap, but as the climate warms, perhaps Pennsylvania will become more hospitable in time, so it's a species worth monitoring closely.

Golden Oyster (*Pleurotus citrinopileatus*)

The **golden oyster mushroom** *(Pleurotus citrinopileatus)*, a very easily identified edible species, is ubiquitous in Pennsylvania and across much of the Midwest, mid-Atlantic, and northeast US, with over 12,000 (and rapidly rising) observations on iNaturalist. Andi Bruce, advised by Dr. Todd Osmundson, at University of Wisconsin-La Crosse, devoted her 2018 master's thesis to studying the population genomics of the golden oyster, following community science data, and exposing this non-native species' spread in the wild as a result of multiple human-mediated introductions. The study of the golden oyster mushroom continues at the University of Wisconsin-Madison, where Ph.D. candidate Aishwarya Verabahu, advised by mycologist Dr. Anne Pringle and US Forest Service research biologist Michelle Jusino, is exploring the negative impacts of golden oysters in the wild.

In general, **oyster mushrooms** (*Pleurotus* spp., of which there are species native to the US and Pennsylvania) are aggressive growers, such that they are the perfect starter species for amateur cultivators. Andi Bruce suggested in her thesis that the process of strain cultivating could have enabled the most aggressive and rapidly growing golden oyster strain to be selected and promoted for commercial use.

Aishwarya Veerabahu has described the golden oyster mushroom as the "Midas mushroom," comparing the fungus to the king in Greek mythology who turned everything he touched into gold, which had unanticipated, undesirable consequences. She found that golden oysters reduced native fungal diversity in the wood of dead elm (*Ulmus* spp.) trees, with trees with golden oysters showing only about half the diversity of those without them. The native mossy maze polypore (*Cerrena unicolor*) and the elm oyster (*Hypsizygus ulmarius*) were particularly impacted. Veerabahu has additional research questions regarding the golden oyster, and you can help her get answers by visiting her website[1].

Asian Beauty (*Radulomyces copelandii*)

The Asian beauty fungus (*Radulomyces copelandii*), a saprotrophic, toothed crust fungus, was apparently first found in the United States by Larry Millman in Massachusetts in 2009. J. Ginns identified it as *Radulomyces copelandii*, which was originally described from the Philippines. Millman proceeded to find the fungus frequently on northern red oak, white oak, and beech in numerous places in Massachusetts. There are now thousands of observations of the fungus on iNaturalist across the northeast to mid-Atlantic, and it is quite abundant in Pennsylvania.

This species also has a few lookalikes: *Basidioradulon radula* and *Sarcodontia amplissima*, the North American sister species to *Sarcodontia setosa* (Nakasone et al., 2021), but the former has a tougher texture with patchier teeth, and the latter is a yellow shade and has a noticeable unpleasant and sometimes sweet odor, according to Gary Emberger's "Fungi Growing on Wood" website, though the page uses the now-erroneous name *S. setosa*.

The invasive **golden oyster mushroom** (*Pleurotus citrinopileatus*) is ubiquitous in Pennsylvania and 24 other states and one Canadian province, with over 12,000 observations on iNaturalist at the end of 2025.

Native to Asia, the **Asian beauty** (*Radulomyces copelandii*) was first observed in North America in 2009. It is a wood-decaying species with delicate, fringed, cream-colored fruiting bodies.

1 https://aishwaryav.org/Published_Research/index.html

Recommendations for Management and Conservation

Management of these aforementioned species has not yet been attempted to my knowledge. However, as with all invasive species, documentation, prevention and slowing the spread helps reduce the shock to the native ecosystem. Baseline data of what species exist where is important to be able to catch new arrivals or to understand changes in the behavior of native species. Fungal species of potential invasive concern, including mushroom-producing species and non-pathogenic species, should be recorded on publicly-available lists more frequently.

Cultivators should avoid using nonnative strains, or at least stick to species that have long been in use without apparent naturalization (shiitake, for example). Potentially, commercial cultivation and purchase of nonnative fungi should be regulated. Cloning fungi from the wild can be a way to utilize hyper-local strains.

Field practices are equally important. When collecting introduced species in the wild, I recommend they be immediately placed into a paper bag and disposed of in the trash once no longer needed. If you are using equipment in an area possessing these species, or any introduced fungi, (or any fungal hitchhikers you don't want) using a 10% bleach solution on equipment between uses may help prevent propagules (spores and mycelium) from establishing.

REFERENCES

Bruce, A. L. (2018). Population genomic insights into the establishment of non-native golden oyster mushrooms (Pleurotus citrinopileatus) in the United States (Doctoral dissertation).

Clifton, E. H., Castrillo, L. A., & Hajek, A. E. (2021). Discovery of two hypocrealean fungi infecting spotted lanternflies, Lycorma delicatula: Metarhizium pemphigi and a novel species, Ophiocordyceps delicatula. Journal of Invertebrate Pathology, 186, 107689.

Emberger, G. (2008). Sarcodontia setosa. Retrieved from https://www.messiah.edu/Oakes/fungi_on_wood/teeth%20and%20spine/species%20pages/Sarcodontia%20setosa.htm

Exec. Order No. 13,112, Volume 64, Number 25 (1999). https://www.federalregister.gov/documents/1999/02/08/99-3184/invasive-species

Nakasone, K. K., Ortiz-Santana, B., & He, S. H. (2021). Taxonomic studies of crust fungi with spines in Radulomyces, Sarcodontia, and the new genus Noblesia. Mycological Progress, 20, 1479-1501.

Pringle, A., Adams, R. I., Cross, H. B., & Bruns, T. D. (2009). The ectomycorrhizal fungus Amanita phalloides was introduced and is expanding its range on the west coast of North America. Molecular Ecology, 18(5), 817-833.

Reiley, L. (2024). Invasive oyster mushrooms are thriving. Ambrook Research. Retrieved from https://ambrook.com/research/environment/golden-oyster-mushroom-invasion

Royo, A. A., Vickers, L. A., Long, R. P., Ristau, T. E., Stoleson, S. H., & Stout, S. L. (2021). The forest of unintended consequences: anthropogenic actions trigger the rise and fall of black cherry. BioScience, 71(7), 683-696.

Taratut, Daniel J., Joseph P. Calabrese, Amy L. Kutay, Brent J. Sewall, and Barrie E. Overton. "Natural and experimental fungal colonisation of Lycorma delicatula egg masses suggests reduced hatch success." Biocontrol Science and Technology 35, no. 11 (2025): 1309-1333.

Veerabahu, Aishwarya, Mark T. Banik, Daniel L. Lindner, Anne Pringle, and Michelle A. Jusino. "Invasive golden oyster mushrooms are disrupting native fungal communities as they spread throughout North America." Current Biology 35, no. 16 (2025): 3994-4002.

Wolfe, B. E., Richard, F., Cross, H. B., & Pringle, A. (2010). Distribution and abundance of the introduced ectomycorrhizal fungus Amanita phalloides in North America. New Phytologist, 185(3), 803-816.

https://andibruce.wordpress.com/

The native **oyster mushroom** (*Pleurotus ostreatus*) is common in Pennsylvania's forests. Cultivation strains are readily available for purchase, and with some extra effort, wild specimens can be cloned to grow at home. However, a word of caution: oysters have been known to grow on water-damaged wood indoors!


Photo by Barbora Batokova

Glossary of Mycological Terms

Structure & Morphology

Terms describing the physical structure and anatomy of fungi and mushrooms.

Agaric – A mushroom with gills on the underside, which release spores for reproduction.

Annulus (Ring) – A ring of tissue that forms around the stipe, remaining from the partial veil that once covered the gills.

Ascocarp – A fruiting body produced by ascomycete fungi. It contains sac-like structures (asci) that develop and release ascospores. Examples include morels, cup fungi, and many lichen fruiting bodies.

Ascomycete – A fungus that produces spores inside microscopic sac-like structures called asci; includes morels, truffles, or cup fungi.

Ascospore – A reproductive spore produced inside an ascus and released to initiate new fungal growth.

Basidiocarp – A fruiting body produced by basidiomycete fungi. It contains the spore-producing cells (basidia), which typically line gills, pores, or spines. Examples include boletes, chanterelles, and bracket fungi.

Basidiomycete – A fungus that forms spores on club-shaped cells called basidia; includes boletes, puffballs, or shelf fungi.

Basidiospore – A reproductive spore produced on a basidium and released into the air to start new fungal growth.

Bolete – A mushroom with a thick, fleshy cap and a sponge-like layer of pores (rather than gills) beneath it; many species form symbiotic relationships with trees.

Chitin – A strong, flexible compound that makes up the cell walls of fungi and the shells of insects and crustaceans.

Conidia – Asexual spores produced on the tips or sides of hyphae, dispersed by wind or water. Also see **spore**.

Dikaryotic – Describes fungal cells that contain two distinct nuclei before they fuse in sexual reproduction.

Fruiting body – The visible reproductive structure of a fungus that produces and disperses spores.

Gills (Lamellae) – Thin, blade-like structures on the underside of a mushroom cap where spores are produced and released.

Gymnothecium – A loosely woven, “naked” fruiting body in which asci and their ascospores develop, characteristic of the genus *Pseudogymnoascus*.

Hypha – A thread-like filament that is the basic structural unit of fungal growth.

Mushroom – Non-scientific term describing the reproductive structure of macro fungi, typically belonging to the phylum Basidiomycota (and some members of the phylum Ascomycota such a morels), that produces and releases spores for reproduction.

Mycelial mat – A dense, felt-like mass of fungal filaments (hyphae) forming typically in soil, wood, or leaf litter.

Mycelium – The branching underground network of hyphae that absorbs nutrients and supports the fungus.

Partial veil – A temporary layer of tissue in developing mushrooms that covers and protects the spore-bearing surfaces (such as gills or pores) until the fruiting body matures, often leaving remnants as a **ring (annulus)** on the stem or fragments on the cap edge.

Pileus (Cap) – The umbrella-like top of a mushroom that protects the spore-bearing surface underneath.

Pores – Small openings under the caps of some fungi (like boletes and polypores) through which spores are released instead of from gills.

Spines / Teeth – Small, pointed projections under the cap of certain fungi (like hedgehog mushrooms) that release spores.

Sporangium – A sac-like structure in which spores are formed and stored before being released.

Spore – A tiny reproductive cell for dissemination. In Ascomycetes and Basidiomycetes the term spore is reserved for when spores are produced by meiosis (sexual reproduction) and the term conidia for when produced by mitosis (asexual reproduction).

Sporocarp – A multicellular structure or “fruiting body” where spores are produced, protected, and eventually released; includes ascocarps and basidiocarps depending on the fungal group.

Stipe (Stem) – The stalk that supports the mushroom cap, elevating it above the ground for better spore dispersal.

Thallus – The main vegetative body of a fungus or lichen, lacking true roots, stems, or leaves.

Universal veil – A membranous tissue that completely encloses an immature mushroom, protecting the developing fruiting body. As the mushroom grows, it breaks apart, often leaving remnants as a volva at the base and patches or warts on the cap surface.

Volva – A cup-like structure at the base of some mushrooms, especially amanitas; a remnant of the universal veil that once enclosed the young fungus.

Yeast – A single-celled fungus that reproduces by budding; widely used in baking, brewing, and research.

Green elfcups (*Chlorociboria* spp.) are Ascomycetes whose small, disc-shaped apothecia appear on decaying hardwood, marking active decay. They also produce a blue-green pigment that stains the wood.

The **powdered sunshine lichen** (*Vulpicida pinastri*) is a bright yellow foliose lichen common in northern peatlands, often growing on alder and other shrubs in full sun. It is rare in Pennsylvania.

Ecology & Environment

Terms related to fungal roles and relationships within ecosystems, including their partnerships, ecological functions, and influence on soil and climate.

Arbuscular mycorrhiza – A symbiotic relationship where fungal hyphae penetrate plant root cells to share nutrients directly via highly branched fungal arbuscules.

Bioremediation – The use of living organisms, such as fungi, bacteria and plants, to break down or remove pollutants from the environment.

Brown rot – A type of wood decay caused by fungi that digest cellulose but leave lignin intact, resulting in dry, brown, crumbly wood.

Carbon sequestration – The capture and storage of atmospheric carbon in soil and vegetation, supported by mycelial growth and mycorrhizal networks.

Commensal – An organism that lives in close association with another species, gaining benefits such as food or shelter while neither harming nor helping its host.

Detritivore – An organism that feeds on decomposing organic matter, aiding in nutrient recycling within ecosystems.

Ectomycorrhiza – A partnership where fungal filaments wrap around the outside of plant roots, exchanging nutrients and water for sugars.

Endophyte – A fungus that lives inside plant tissues.

Entomopathogenic fungi – Fungi that infect and kill insects, naturally regulating pest populations.

Funga – All the fungi present in a particular region, habitat, or geological period. The term serves as a counterpart to "flora" (plants) and "fauna" (animals) for the fungal kingdom, used in scientific and conservation contexts to denote the fungal diversity of an area.

Fungal network – The underground web of mycelium connecting plants and fungi, allowing the exchange of nutrients, water, and communication signals.

Fungicolous fungi – Fungi that live on or within other fungi, sometimes as parasites or commensals.

Fungivory / Fungivore – The act of feeding on fungi; an organism that consumes fungi. Examples include certain insects, mammals (including humans), or gastropods that eat mushrooms or mycelium.

Gadgil effect – A phenomenon in which ectomycorrhizal fungi suppress the decomposition of organic litter in forest soils by outcompeting saprotrophic fungi for nutrients, potentially slowing nutrient cycling and increasing soil carbon storage.

Heterotroph – An organism that cannot produce its own food and instead obtains energy and nutrients by consuming other organisms or organic matter. All fungi, animals, and nonphotosynthetic plants are heterotrophic.

Hyperparasite – A parasite that infects another parasite, such as a fungus attacking another pathogenic fungus.

Lichen – A dual organism made up of a fungus and an alga or cyanobacterium, living together in a mutually beneficial relationship.

Mycobiont – The fungal component of a lichen or of a mycorrhizal association. It provides the structure, protection, and access to minerals or water for its photosynthetic partner.

Mycorrhiza – A typically mutualistic association between fungi and plant roots where both partners exchange nutrients and energy.

Parasite – An organism that lives on or in another organism, feeding off it and potentially causing harm.

Pathogenic fungi – Fungi that invade and cause disease in other living organisms.

Photobiont – The photosynthetic partner in a lichen, which may be an alga (phycobiont) or a cyanobacterium (cyanobiont). It provides carbohydrates to the fungal partner through photosynthesis.

Pioneer fungi – The first fungal species to colonize new or disturbed environments (such as burned areas or bare rock), playing a key role in starting decomposition and enabling later ecological succession.

Pyrophilous fungi – Fungi that thrive after fire events, decomposing burned material and enriching the soil.

Rust fungi – Parasitic fungi of the order *Pucciniales* that infect plants, producing orange or reddish spore masses on leaves and stems.

Saprotroph – A fungus that feeds on and decomposes dead organic matter, recycling nutrients back into the environment. Also called a **saprobe**.

Symbiont – Any organism involved in a close, long-term relationship with another, whether beneficial, neutral, or harmful.

Symbiosis – A close biological relationship between two or more species that can be beneficial (mutualistic), neutral (commensal), or harmful (parasitic), though the term is often used in the mutualistic sense.

White rot – A form of fungal wood decay that breaks down both lignin and cellulose, leaving pale, fibrous wood.

Applied Mycology & Scientific Practice

Terms describing how fungi are studied, used, and applied in science, restoration, biotechnology, and sustainable innovation.

Myceliotronics – A new area of research exploring how fungal mycelium can conduct electricity and be used in eco-friendly electronics.

Mycocontrol – The use of beneficial fungi to suppress harmful pests and plant pathogens naturally.

Mycofabrication – The use of mycelium to produce sustainable materials for packaging, design, or architecture.

Mycofiltration – Using fungal networks to filter pollutants from air, water, or soil.

Mycoforestry – Forest management practices that include fungi to support soil health, tree growth, and biodiversity.

Mycoherbicide – A biological herbicide derived from fungi that targets specific unwanted plants.

Mycoinsecticide – A biological pest control method using fungi that infect and kill harmful insects.

Mycoleather – A leather-like, biodegradable material made by growing and processing fungal mycelium.

Mycologist – A scientist who studies fungi, their diversity, ecology, and potential applications. This includes community scientists and those trained in a university. Lichenologists and plant pathologists are also specialized mycologists.

Mycology – The branch of biology dedicated to studying fungi, including their genetics, ecology, and usefulness in science and industry.

Mycomaterial – Any material made from fungal biomass or mycelium, usually as a renewable alternative to plastics or animal-based products.

Mycoparasite – A fungus that parasitizes another fungus, sometimes helping control harmful fungal species.

Mycopesticide – A pesticide derived from fungi or fungal compounds used for sustainable pest control.

Mycophagy – The act of eating fungi, practiced by both humans and animals; includes wild and cultivated mushrooms.

Mycoremediation – Using fungi to clean polluted soils and water by breaking down contaminants and absorbing toxins.

Mycorestoration – The use of fungi to restore damaged ecosystems by rebuilding soils and promoting plant regrowth.

Mycotechnology – The field that applies fungal biology to develop sustainable technologies and products.

Mycotextile – A fabric-like material made from fungal fibers, providing a biodegradable alternative to synthetic textiles.

The glossary draft was compiled with ChatGPT and further edited and revised for accuracy by Jerry Hassinger, Dr. Barrie Overton, Hannah Huber, and Barbora Batokova.

SOURCES

The Importance of Fungi Booklet

Hunting Mushrooms: How to Safely Identify, Forage and Cook Wild Fungi

Glossary of Mycological Terminology – First Nature

Glossary of Mycological Terms – University of Adelaide

MushroomExpert Glossary

Wikipedia Mycology Glossary

Photo by Barbora Batokova

Photo by Devin Hilty

Photo by Jared White

Photo by Stephen Bucklin

Photo by Josh Doty

Discover. Document. Protect.

Pennsylvania's funga is a vital part of our ecosystems, yet much of it remains unknown, unstudied, and unprotected. Your observations and curiosity help advance fungal conservation. **Get involved.**

Pennsylvania Natural Heritage Program (PNHP)

Access conservation data, species accounts, and ecological community information from the state's authority on rare and endangered species—and help integrate fungi into statewide conservation planning.

Fungal Diversity Survey (FUNDIS)

Explore rare and threatened fungi across North America and use standardized protocols, curated projects, and ID tools to help generate conservation-quality fungal data.

SPUN Underground Atlas

Visualize mycorrhizal fungal diversity worldwide and explore how belowground networks support ecosystems—an invaluable tool for understanding ecological context and informing conservation.

iNaturalist

Contribute to community science and help fill critical data gaps by sharing observations that support research, conservation assessments, species distribution modeling, and long-term biodiversity tracking.

Mushroom Observer

Share detailed fungal observations, compare identifications with the community, and contribute to a long-term, open-access database that supports research, taxonomy, and documentation of fungal diversity.

Local mycology clubs

Join guided forays, build identification skills, and participate in community-based fungal monitoring that strengthens local knowledge and contributes valuable ecological data.

PABS Pennsylvania Biological Survey