



Fungal Collections and Conservation



Figure 1. An herbarium cabinet containing fungal specimens. The individual specimens are in white boxes inside the cardboard shelf boxes. The rubber gasket around the door prevents water and insects from entering the cabinet. Sam Mitchel Herbarium, Denver Botanic Gardens (photograph by B. Thiers).

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Fungi play critical roles in ecosystems as decomposers, symbiotic partners, and sources of medicine, food, and bioactive compounds. However, until recently, fungi were often overlooked in conservation efforts compared to more charismatic taxa like mammals, birds, and plants. The unique structure and life cycle of fungi pose challenges to scientific research, complicating the development and evaluation of conservation strategies. Preserved fungal specimens provide taxonomic, geographical, and historical insights into fungal diversity and changes over time, making them essential for fungal conservation.

Preserved Collections Document Fungal Biodiversity

Preserved specimens consist of dried tissue, either whole reproductive structures or parts, typically stored in light-, water-, and insect-proof cabinets (Figure 1). Fungal specimens may also be found on permanent microscope slides or, rarely, preserved in fluid (Figure 2). Using data from *Index Herbariorum* (Thiers, 2025), it is estimated that 15 to 20 million preserved fungal specimens exist across approximately 3,900 herbaria and fungaria worldwide. The term “herbarium” traditionally refers to preserved plant collections; because fungi were considered plants for most of their history (the earliest known herbarium dates to the mid-1500s), they have traditionally been included in herbaria. The term “fungarium” is now often used for collections that consist solely of fungi.

Most fungal specimens are housed in herbaria or fungaria in Europe



Figure 2. A type specimen of a marine fungus, *Arenariomyces triseptatus* Kohlmeyer. This tiny fungus is preserved in a small vial of sand and beach debris, and also on microscope slides. William and Lynda Steere Herbarium, New York Botanical Garden (photo made available under the Creative Commons license CCBY).

and North America. The Royal Botanic Gardens at Kew, England, may hold the largest collection in the world, with an estimated 1.25 million specimens. Other significant collections are located at the Muséum Nationale d'Histoire Naturelle in Paris and the Komarov Institute in St. Petersburg. In North America, the largest collection is the U.S. National Fungus Collection at the USDA's Beltsville Laboratory, along with large holdings at Harvard University, the New York Botanical Garden, and the University of Michigan. Significant and growing collections are also found in Argentina, Australia, Brazil, China, Colombia, South Africa, and Thailand (Thiers, 2025).

Over the past 20 years, access to these specimens has dramatically improved through a global effort to digitize collections and share the resulting data online. Digitization involves transcribing specimen information into a structured database, typically including the scientific name, collection location, collector's name, date, and description of the fungus in its living state. The data structure follows the international Darwin Core standard developed for preserved biological collections (Darwin Core, 2025). Between 2011 and 2021, the National Science Foundation funded two large grants that

facilitated the digitization of most U.S. fungal specimens and the development of MyCoPortal, enabling free access to these data for everyone with an internet connection (Miller and Bates, 2017).

The Role of Preserved Specimens in Fungal Conservation

Preserved specimens give us the names of fungi.

Conservation efforts rely heavily on a well-documented naming system for fungi. The rules governing the naming of new species mandate that each new species be documented by a designated preserved specimen, known as a type specimen, that is deposited in a recognized, publicly available collection. Other researchers are then able to examine type specimens to make their own analyses. While type specimens are crucial for anchoring the name to a physical entity, such specimens alone are usually not sufficient to fully characterize a species. Understanding the range of variation within a species requires examination of a broad array of preserved specimens from various habitats, geographical locations, and growth stages. The keys and descriptions used by fungal conservationists to confirm the identity of potentially endangered species largely come from analyses of a range of specimens of a species.

Preserved specimens provide insight into how the distribution and diversity of fungi have changed over time.

The availability of large amounts of digitized specimen data from fungal specimens that is now available has permitted a broad range of analyses to help us detect trends over time across wide historical and geographical scales. This is an important source of information for the assessment of fungal rarity. The International Union for the Conservation of Nature, which maintains a list of species that are in danger of extinction, now includes 1,000 fungal species on that list (International Union for the Conservation of Nature, 2025). For each of these fungi, it was necessary to determine its correct name, where it exists, and to predict the future of the fungus, given known threats to its habitat.

Fungal specimens give us insight into fungal evolution and adaptation.

Recognizing that it is impossible to conserve individual species without conserving intact ecosystems, conservation mycologists endeavor to understand the interactions among species that are critical to sustaining ecosystems, and what factors may cause the geographic range of a fungus to expand or contract. Clues to the role of a fungus and its ability to adapt to a changing environment may be found by studying its genetic makeup. The ability to derive DNA from preserved specimens began in the 1980s and the process has been refined greatly since that time to permit extraction from a wider range of organisms and older specimens. DNA sequence comparisons revolutionized the classification of many groups of organisms, including fungi, giving us new insight into how different groups of fungi have evolved. The ability to sequence entire genomes of organisms has allowed an even finer comparison of species and has permitted the association of genes with structures of and functions of organisms. The fungal genome is relatively small (Mohanta and Bae, 2015), and DNA as it exists in dried specimens is well-suited to whole genome sequencing.



Figure 3. A modern herbarium specimen of an Australian bolete specimen, *Tylopilus phaseolisporus* (T.H. Li, R.N. Hilton & Watling) Osmundson, Bougher, R. Rob. & Halling by R. Halling. The specimen label contains a detailed text description of the fungus in the living condition. William and Lynda Steere Herbarium, New York Botanical Garden (photo made available under the Creative Commons license CCBY).

Therefore, dried fungal specimens have the potential to provide insight into the roles that fungi play in ecosystems and perhaps identify the presence and evolution of traits that help fungi survive in different environments (Staats, 2013).

Fungal collections do not encompass all fungal diversity.

The primary limitation of preserved collections as a resource for fungal conservation is that not all fungal species are documented by specimens, and some may never be. Despite centuries of effort in collecting and naming fungal species, most experts agree that a significant portion of fungal biodiversity remains unnamed and undocumented. These fungi may reside in soil or water or within other organisms and may never produce identifiable structures for specimen collection. Estimates of the number of fungal species worldwide range from one to three million (Blackwell, 2011). Currently, only about 150,000 of these species (12% or less) are named, highlighting our inability to capture a vast amount of fungal biodiversity through traditional methods (Lofgren and Stajich, 2021).



Figure 4. Field photograph of *Tylopilus phaseolisporus* of the specimen shown in Figure 3 illustrating the stature, colors, and texture of the fungus (photograph by Roy E. Halling).

We Can Extend Preserved Specimens to Facilitate Their Value to Conservation

Contribute more genetic data.

Sequencing DNA from existing fungal collections can help identify at least some of the still unknown fungal species. Sequencing of type specimens for this work is especially important. DNA sequences can be uploaded to a repository such as GenBank, where users can “blast” an unknown gene sequence against existing data to find matches, ideally with named species. This identification can unlock additional information about the species, sourced from specimen data repositories like MyCoPortal, observations logged on platforms such as iNaturalist (iNaturalist, 2025) or Mushroom Observer (Mushroom Observer, 2025), and literature databases such as MycoBank (MycoBank, 2025) or the Biodiversity Heritage Library (Biodiversity Heritage Library, 2025). The Royal Botanic Gardens at Kew, in collaboration with the Natural History Museum of London and the Royal Botanic Gardens at Edinburgh, is sequencing the DNA of thousands of fungal specimens held in their repositories (Royal Botanic Gardens, Kew, 2025). Efforts are also underway in several U.S. herbaria, notably the Harry D. Thiers Herbarium at San Francisco State University and the University of Michigan Herbarium (Russell, 2025).

Link fungal specimens to all derivative data.

Fungi change drastically in appearance upon drying; their colors, textures, and stature may be difficult to reconstruct from dried specimens alone. Therefore, best practices for making fungal collections have always included a text description of the living fungus, along with photographs (or watercolor paintings in earlier days), spore prints, and color references to a standard (Figures 3 and 4). Some of this supplementary data is stored with the specimen, while other notes may be kept on filing cards, in field books and physical or digital photographic archives. When such data about specimens are not stored together, the connections

SAM MITCHEL HERBARIUM OF FUNGI



Figure 5. Ed and Ikuko Lubo and Dr. Andrew Wilson in the Sam Mitchel Herbarium of Fungi at the Denver Botanic Gardens. The founder and namesake of this collection, Sam Mitchel, was a physician with a strong dedication to documenting the fungi of Colorado. The tradition of involvement of the local mycological community and the scientists at the Garden has continued Mitchel's vision for the collection. Ed and Ikuko identify, process, and file specimens and help to train students and other hobbyists who volunteer in the collection (photo by B. Thiers).

among them may become lost over time. Thus, it is crucial to digitize supplementary data along with the specimens. Once digitized, these data, along with others such as gene sequences and images of diagnostic microscopic structures, can be linked digitally to the specimen record, thereby expediting identification and analysis of the species. Some MyCoPortal specimen records already include such elements, but many more can be enhanced this way.

Link to environmental data resources for collection sites.

By characterizing the geographic location of a specimen collection, especially if georeferenced (i.e., identified by latitude and longitude), we can link to a broad range of data from other digitized collections of organisms that may coexist at that site, aiding in the characterization of the ecosystem. This georeferenced locality can also connect to

data on rainfall patterns, soils, geological history, past land use, and documented sources of disturbance or pollution. The establishment of an extended network to connect conservation-relevant data to biological specimens was proposed in 2018 and is the focus of ongoing efforts of the international collections community (Hardisty et al., 2022). While such a network may be several years away, fungal collections and conservation objectives can drive progress by providing compelling arguments for access to this data.

In Order to Continue to Serve Research on Fungal Biodiversity and Conservation, Collections Must Continue to Exist

A large part of the fungus herbarium of the Berlin Botanical Garden was destroyed, along with most of the herbarium, by Allied Forces bombs in 1944 (Hiepko, 1987). There are quite a few herbaria, some of which certainly contain fungi, about which no information has been available to *Index Herbariorum* for more than a decade, and it is possible that some of these collections no longer exist. Remarkably though, despite centuries of world conflicts, natural disasters and changes in priorities in science, most fungal specimens that have ever been preserved in herbaria and fungaria still exist and can be located for study.

However, we have seen a trend over time in the constriction

of resources for biological collections, and we should not take for granted that just because specimens still exist now that they are secure for the future. Uncertain economic environments elevate the worry that other collections-holding institutions might, like Duke University (Thiers et al., 2024), wish to offload their specimens to another institution. What will happen if no other institution has the capacity to accept them?

Even if collections are not discarded wholesale, they may be destroyed through neglect.

Fungal collections are highly subject to infestation by molds and consumption by insects, especially the herbarium beetle (*Trogoderma angustum*). Specimens that do not receive active monitoring and remediation may be lost even when the collection appears to remain intact. Digitization has ensured that much critical information about our fungal collection's heritage is preserved, but examination of the physical specimen is still required for many specimens to document morphological structures and DNA sequences. We must continue to update those databases to reflect new collections and new knowledge.

To ensure that our wealth of fungal specimens is cared for and utilized to their fullest potential in preserving fungal diversity, we must continue to promote their value for both conservation and human health. Fungi have fascinated people for centuries; consequently, our extensive knowledge of fungi has been developed largely by those studying them as a hobby rather than a profession. Community mycologists have played a key role in documenting fungal biodiversity for centuries and are currently active in fungal conservation through initiatives like the Fungal Biodiversity Survey (2025).

In fungaria such as the Sam Mitchel Herbarium at the Denver Botanic Gardens (2025), staff encourage and incentivize the participation of fungal enthusiasts in caring for and expanding the collection by providing access to expertise, library resources, and equipment (Figure 5). We are at a time of heightened interest in fungi and significant needs for collections, suggesting that engagement benefiting both community members and fungal collections is ripe for expansion. This engagement could enhance personal enjoyment and knowledge while helping to preserve the earth's fungal biodiversity.

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