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# Fungal conservation in the USA

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ABSTRACT: Over the last 30 years there has been increasing action in the arena of fungal conservation globally, leading to a higher profile for fungi in conservation efforts. After reviewing the status of fungal conservation in the USA it is clear that further development and implementation of measures to conserve fungi are needed. This field remains under-developed in the USA due in large part to outdated misperceptions of fungi as organisms that are unknown and unknowable. Using examples from the literature, the notion of fungal inscrutability is dispelled and specific actions that should be undertaken to advance fungal conservation in the USA are outlined.

KEY WORDS: Endangered Species Act · Micheli Guide · Natural Heritage Program · NatureServe · Rio Convention

## INTRODUCTION

Fungi are among the most biologically diverse and ecologically significant organisms on the earth (see Heilmann-Clausen et al. 2015). They form mutualistic symbioses with almost all land plants and many animals, are primary decomposers in terrestrial ecosystems, and rank among the largest organisms known (van der Heijden et al. 1998, Hättenschwiler et al. 2005). The broad importance of fungi transcends basic measures of taxonomic diversity and ecosystem services to include medical and industrial applications as well as deep-rooted connections to human cultures (Hufford 2000, Emery & McLain 2001, Pieroni et al. 2005). Despite the magnitude of the ecological and economic benefits they provide, and the fascination they generate from scientists and the public alike for centuries, fungi have been virtually excluded from conservation consideration and planning.

In the past 30 years, worldwide interest in the conservation of fungi has steadily grown (Scheidegger et al. 1995, Arnolds 2001, Moore et al. 2001, Watling 2005, Molina 2008, Barron 2011, Heilmann-Clausen et al. 2015). This is evidenced by the many fungal conservation groups established during this period, including the European Council for the Conservation of Fungi, the International Union for Conservation of Nature's (IUCN) Fungal Committee, and the International Society for Fungal Conservation. The continued activity and expansion of such groups illustrates the increasing understanding of the importance of fungi across academic, political, and public spheres (Lizon 1995, Barron 2011, Minter 2012, Mueller et al. 2014, Heilmann-Clausen et al. 2015). It concurrently highlights the increased recognition that fungi, like other ecologically important organisms long considered inscrutable, must be included in conservation planning.

Here we summarize the current state of fungal conservation in the USA at federal and state levels. We discuss the misconception of fungal inscrutability, including specific examples that illustrate we have sufficient knowledge to conserve certain groups of fungi or regions with high fungal diversity. We also provide a series of recommendations

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that illustrate how fungal conservation in the USA could be advanced. Specifically, we suggest large-scale educational programs, increased training of professional mycologists, and regular communication with policy-makers and land managers. Considering the ever increasing habitat loss and degradation coupled with imminent threats from a rapidly changing climate, we argue that immediate action is merited to include fungi in conservation strategies.

## FUNGAL CONSERVATION IN THE USA: FEDERAL SYSTEMS

At the federal level the only mechanism through which fungal conservation is currently effected is the Endangered Species Act (ESA). The ESA was established in 1973 to protect, and facilitate the recovery of, threatened and endangered species (USFWS 2013a). Since it was enacted only 2 species of fungi have been listed under the ESA: *Cetradonia linearis* (rock gnome lichen) and *Cladonia perforata* (Florida perforate cladonia). Both of these are endemic to small areas of eastern North America and both are threatened by multiple forces (USFWS 2007, 2013b). *Cetradonia linearis* only occurs in the southern Appalachian Mountains, while *Cladonia perforata* is restricted to the Coastal Plain of Florida. Considering that there are >37 000 documented species of fungi in the USA, they are underrepresented in the ESA listing compared to most other organismal groups (Table 1).

Although 2 fungi are listed under the ESA and most of their populations are on protected public lands, few resources have been devoted to research that would facilitate their conservation and recovery. In the case of *Cetradonia linearis*, successful efforts were undertaken by local land managers to locate new populations of this species once it was listed, but only a small fraction of the total known populations are monitored. Most aspects of the biology of the species (e.g. demography, life history, growth rates) remain unstudied (USFWS 2013b). *Cladonia perforata* has received more study than *C. linearis*. A small number of populations of *C. perforata* are monitored, and some studies of the basic biology of the species have been undertaken (Yahr 2000, USFWS 2007). Although both fungi have been listed for 20 or more years, very little research and action has occurred to meet the goals of the Species Recovery Plans developed as part of the ESA listing.

## FUNGAL CONSERVATION IN THE USA: STATE SYSTEMS

Although fungi are largely excluded from the existing federal conservation framework, mechanisms exist at the state level that can also affect fungal conservation. At the state level, the task of considering, monitoring, and ensuring the continued existence of threatened and endangered fungal species largely relies on decisions made by landowners and land managers. Most land managers do not have extensive training in fungal diversity, and thus rely on conservation databases if they consider it important to include fungi in conservation planning. In the USA each state has a Natural Heritage Program (NHP) that maintains data on local species and ecosystems that are of conservation concern.

The NHP system was founded by The Nature Conservancy in 1974 as the Natural Heritage Network (Groves et al. 1995). The goals of this network are to maintain detailed information about rare species and ecosystems in each state, and identify conservation priorities. In most states, the network eventually changed hands from The Nature Conservancy to an appropriate agency within the state government, such as the Department of Natural Resources. Although in many cases the hubs of the network changed hands at the state level, all of the NHPs are still coordinated by NatureServe, a large, non-profit organization. NatureServe also maintains the databases of rare species and ecosystems. These data are assembled from a variety of sources including government-employed scientists, consultants, and published literature. There are many fungi included in NatureServe (1685 US species and 4269 North American species as of 10 November 2014; Table 1); however, all are ranked as having a status of 'incomplete distribution data' and many lack conservation status (i.e. Faber-Langendoen et al. 2012).

Drawing from NatureServe and resources at the state level, each state NHP maintains a list of species within its borders that are considered to be extirpated, endangered, threatened, or of special concern. In many cases the occurrences and statuses of species on NHP state lists are tracked, discussed at annual meetings of scientists, and routinely updated. The collective NHP lists in each state include thousands of species of plants and animals, from birds to freshwater mussels to filmy ferns (see Supplement 1 at www.int-res.com/articles/suppl/n028p033_supp.pdf). Fungi, however, are absent from most state lists. The state lists that do include fungi generally have fewer than a dozen species (Fig. 1),

Table 1. Comparison of the approximate number of US species (data from summary in Stein et al. 2000, except for vertebrate groups which were not categorized in that publication; NatureServe data used under the assumption they accurately represent vertebrate diversity), number of taxa (including infraspecifics) listed under the Endangered Species Act (ESA; as of November 2014), the number of US taxa (including infraspecifics) and the number of North American (USA & Canada; including infraspecifics) included in the NatureServe database (as of November 2014). Percentages of (1) US species listed under the ESA, (2) US species included in NatureServe, and (3) US taxa versus all taxa included in NatureServe are given in columns V, VI, and VII. Column headings as follows — I: approximate number of US species (estimates from 2000); II: number of taxa listed under the ESA (2014); III: number of US taxa in NatureServe (2014); IV: total number of taxa in NatureServe (2014); V: percent of US taxa listed under the ESA; VI: percent of US taxa in NatureServe; and VII: percent of total taxa in NatureServe represented by US taxa

| | I | II | III | IV | V (%) | VI (%) | VII (%) |
|---|---|---|---|---|---|---|---|
| **ANIMALS** | | | | | | | |
| **Vertebrates** | | | | | | | |
| Mammals | 957 | 95 | 957 | 1080 | 9.93 | 100.00 | 88.61 |
| Birds | 1080 | 98 | 1080 | 1183 | 9.07 | 100.00 | 91.29 |
| Reptiles | 643 | 40 | 643 | 694 | 6.22 | 100.00 | 92.65 |
| Amphibians | 378 | 35 | 378 | 412 | 9.26 | 100.00 | 91.75 |
| Fishes | 1527 | 157 | 1527 | 2288 | 10.28 | 100.00 | 66.74 |
| **Total vertebrates** | **4900** | **425** | **4585** | **5657** | **8.67** | **93.57** | **81.05** |
| **Invertebrates** | | | | | | | |
| Insects | 96406 | 75 | 12788 | 18941 | 0.08 | 13.26 | 67.51 |
| Arachnids | 9557 | 12 | 1196 | 9423 | 0.13 | 12.51 | 12.69 |
| Crustaceans | 9675 | 25 | 1037 | 1071 | 0.26 | 10.72 | 96.83 |
| Other invertebrates | 28262 | 136 | 3459 | 3581 | 0.48 | 12.24 | 96.59 |
| **Total invertebrates** | **143900** | **248** | **19743** | **27445** | **0.17** | **13.72** | **71.94** |
| **PLANTS** | | | | | | | |
| **Vascular plants** | | | | | | | |
| Gymnosperms | 114 | 3 | 194 | 199 | 2.63 | 170.18 | 97.49 |
| Ferns and fern allies | 556 | 30 | 844 | 859 | 5.40 | 151.80 | 98.25 |
| Angiosperms | 15320 | 848 | 28271 | 28814 | 5.54 | 184.54 | 98.12 |
| **Total vascular plants** | **15890** | **881** | **29309** | **29872** | **5.54** | **184.45** | **98.12** |
| **Non-vascular plants** | | | | | | | |
| Mosses | 1400 | 0 | 1164 | 1642 | 0.00 | 83.14 | 70.89 |
| Liverwarts | 700 | 0 | 566 | 762 | 0.00 | 80.86 | 74.28 |
| Hornworts | 11 | 0 | 13 | 20 | 0.00 | 118.18 | 65.00 |
| **Total non-vascular plants** | **2111** | **0** | **1743** | **2424** | **0.00** | **82.57** | **71.91** |
| **FUNGI** | | | | | | | |
| Lichenized fungi | 3800 | 2 | 1563 | 4135 | 0.05 | 41.13 | 37.80 |
| Non-lichenized fungi | 34000 | 0 | 122 | 134 | 0.00 | 0.36 | 91.04 |
| **Total fungi** | **37800** | **2** | **1685** | **4269** | **0.01** | **4.46** | **39.47** |

nearly all of them lichens, and in many instances these fungi are classified together with plants due the historical definition of 'botany' as including plants and fungi, despite strong evidence that fungi are actually more closely related to animals than plants.

## FUNGAL CONSERVATION IN THE USA: SUMMARY

From legislative and policy perspectives fungal conservation in the USA lags behind its counterparts in Canada, parts of Europe, Scandinavia, and eastern Asia (e.g. COSEWIC 2006, Dahlberg et al. 2010). For instance, in the United Kingdom fungi have been added as an essential element to include when evaluating Sites of Special Scientific Interest (Bainbridge et al. 2013). In the USA, at the federal level, there is only one active law that pertains to fungal conservation, the ESA, which currently lists 2 fungal species. A second federal law, the Survey and Manage program of the Northwest Forest Plan, listed and managed 315 species of fungi. That program functioned for over a decade before being terminated and then subjected to protracted litigation that remains to be fully resolved (BLM 2013).

How does fungal coverage under the ESA rank compared to legislation from other nations? The International Society for Fungal Conservation devel-

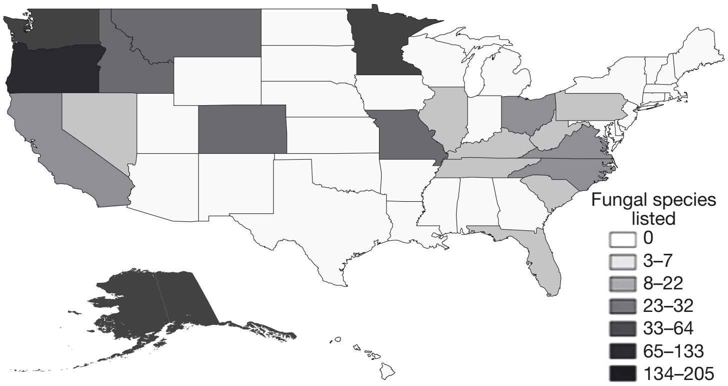


Fig. 1. Number of species of fungi tracked by the Natural Heritage Program (NHP) in each state as threatened, endangered, or of concern. These numbers do not include potential candidates or 'watch' species and are based on lists accessed on 1 November 2014. The sources of data used to generate this map are available in Supplement 1 at www.int-res.com/articles/suppl/n028p033_supp.pdf

oped the Micheli Guide (ISFC 2013, Minter 2014) as a tool to assess how well legal conservation documents make provisions for fungi. This assessment has been applied to documents from all 168 countries that have signed the Convention on Biological Diversity, which only leaves the USA to be assessed (UNEP 1992, ISFC 2013, Minter 2014). The USA did not sign the Convention; thus, its legal conservation framework has not been evaluated using these guidelines. Criteria for evaluation include how frequently keywords relating to fungi (vs. keywords relating to plants and animals) are mentioned in the text, if fungi are recognized as a distinct 'biological kingdom', and if plans are outlined to advance fungal conservation to the same level as for plants and animals. The possible outcomes range from rankings of 'good' to 'totally deficient'.

We applied the Micheli Guide to the ESA and found that its rank is 'totally deficient' (see Supplement 2 at www.int-res.com/articles/suppl/n028p033_supp.pdf). Thus, the ESA lacks provisions for an entire kingdom of life. The USA is not alone in its lack of fungal conservation provisions. Of the documents from countries that signed the convention, none have ranked as 'good' or 'adequate,' 3 ranked as 'nearly adequate,' 5 ranked as 'poor,' 27 ranked as 'deficient,' 62 ranked as 'seriously deficient,' and 32 ranked as 'totally deficient' (ISFC 2013). Although fungi have received increasing attention, exclusion from conservation remains a global issue. Short of separate legislation from the United States Congress, similar to acts protecting migratory birds or marine mammals, the ESA is the most important document to revise to improve fungal conservation in the country.

The startling degree to which fungi are excluded from conservation frameworks in the USA is illustrated by comparing the number of species of different organismal groups that occur in the country with the numbers of species protected under the ESA (i.e. not necessarily state or federally listed) and included in NatureServe (Table 1). Of the approximately 37 800 species of fungi known from the USA (Stein et al. 2000) only 4.46% are included in NatureServe and 0.01% are listed by the ESA. These numbers are only comparable to invertebrates (13.72 and 0.17%, respectively), which is another example of an understudied biodiverse group that is underrepresented in conservation planning.

Recognizing that policies and regulations in the USA remain underutilized with respect to fungal conservation, we devote the remainder of this article to (1) explaining why this paralysis exists, (2) providing a case study detailing why a specific group of fungi should be conserved and what measures could be implemented to achieve this goal, and (3) outlining specific actions to overcome this impasse.

## DISPELLING THE MYTH OF FUNGAL INSCRUTABILITY: CASE STUDY OF CYANOLICHENS

One of the best documented and most readily observed losses of fungi involves species that form mutualistic symbiotic relationships with cyanobacteria (cyanolichens). About 20% of all fungi have adopted the lichen lifestyle of forming a symbiosis with an alga or cyanobacteria, although only a small fraction associate with the latter (Lutzoni et al. 2001). Lichens grow in terrestrial ecosystems worldwide (Brodo et al. 2001), where they function as a food source and camouflage for animals (Henderson & Hackett 1986, Cumming 1992, Pettersson et al. 1995), sensitive indicators of environmental quality and change (Will-Wolf et al. 2006), and habitat for a diverse community of endophytic fungi, bacteria, and invertebrates (Arnold et al. 2009, Hodkinson & Lutzoni 2009). Cyanolichens, in particular, contribute significantly to ecosystems through participation in the nitrogen cycle by fixing nitrogen from the air (Nash 1996).

Since the late 1800s it has been well documented that cyanolichens are particularly sensitive to air pollution, especially acid rain caused by sulfur dioxide and nitrogen oxide (Seaward & Letrouit-Galinou 1991, Richardson & Cameron 2004). Acid rain has a compounding negative effect as it directly affects the lichen while concurrently lowering the pH of its substrate (Richardson & Cameron 2004). In addition to acid rain, cyanolichens are highly sensitive to other disturbances, such as timber harvesting, and are slow to recolonize forests that have been logged due to limited dispersal ability; in Oregon it was shown to take 70 to 110 years for cyanolichens to begin to recolonize harvested forests (Peterson & McCune 2001). While forest management strategies have been developed to prevent total loss of lichens from logged forests (Hilmo et al. 2011, Fedrowitz et al. 2012, Larsson et al. 2014), these require implementation on large scales to be effective, which has not yet occurred in the USA.

Acid rain and timber harvesting can be managed to improve the health and abundance of cyanolichens. Acid rain can be mitigated by reduction of coal burning and other sulfur-dioxide-containing emissions. This lies in the realm of emissions regulation, which is an active policy area in the USA. Logging impacts can also be regulated and reduced, with the most important step being to end all logging of remaining old-growth forests. Some old-growth forests harbor high lichen diversity and are the last strongholds for cyanolichens (Lesica et al. 1991, Radies & Coxson 2004).

The sources of negative impacts to cyanolichen diversity and viable solutions to these threats are clear and supported by a strong foundation of data and research. Why, then, is there no coordinated national effort to conserve these important fungi like those that exist for other groups of organisms (e.g. the Marine Mammal Protection Act of 1972 and the Migratory Bird Treaty Act of 1918)? This is a particularly salient question because many other groups of organisms rely directly and indirectly upon lichens (Sharnoff 1994).

## THE MYTH OF 'UNKNOWABLE FUNGI' FORESTALLS CONSERVATION

There is a stark disparity between the immense, calculable importance of fungi and the lack of attention from conservation efforts in the USA. In our experience this disparity stems from prevailing assumptions that (1) biodiversity patterns of fungi mirror those of other more frequently studied groups, (2) we know too little about them, (3) the task of establishing knowledge parity with groups such as mammals and plants is completely intractable, and (4) the 'everything is everywhere' hypothesis applies to fungi. Common assumptions such as these explain why conservation efforts have marginalized or ignored understudied groups such as fungi (Myers et al. 2000, Barron 2010, Caro 2010).

The assumption that understudied groups mirror the diversity patterns of better studied groups is a major hurdle to the recognition of the need to specifically study and conserve groups like fungi. Fungal diversity patterns that follow those of plants and vertebrates do exist (e.g. Pickering et al. 2002). However, many studies have shown that lesser studied organisms do not follow the diversity patterns of plants and animals at both small and large spatial scales (Pharo et al. 1999, Rozzi et al. 2008, McGuire et al. 2012, Lendemer & Allen 2014). As long as we continue to assume that diversity patterns of understudied groups match those of plants and animals, our conservation assessments and decisions will remain incomplete and inaccurate.

There are numerous examples of fungi in the USA whose taxonomy, biology, and distribution are known well enough to produce useful conservation assessments (e.g. Molina 2008, Lendemer et al. 2014; Fig. 2). This applies to common and widespread species that are of no conservation concern (e.g. Norvell 1995, Buyck et al. 2006), just as it does to species for which declines and threats have been well documented (e.g. Lilleskov et al. 2001, Richardson & Cameron 2004). Although basic research is still needed to advance knowledge of fungi to the level of other kingdoms, the listing of 2 fungi under the ESA, the documented declines of species, and the multitude of well-known species all clearly illustrate that fungi are far from data deficient (Wilcove & Master 2005).

Further evidence that the notion of fungi as 'unknown and unknowable' is erroneous comes from the identification of fungal biodiversity hotspots in many parts of the world. The discovery of such hotspots not only suggests areas which should be placed as high conservation priorities, but illustrates that we can delineate hotspots in terms of both extent of geography and biological diversity (de Carvalho et al. 2012, Tedersoo et al. 2012, Lendemer et al. 2013, Lendemer & Allen 2014). Two of these hotspots, regions with exceptional diversity of fungi, are located in the eastern USA, a region otherwise characterized by extensive historical and ongoing alteration of natural habitats (Lendemer et al. 2013, Lendemer & Allen 2014). These studies clearly illustrate that fungal conservation can be approached

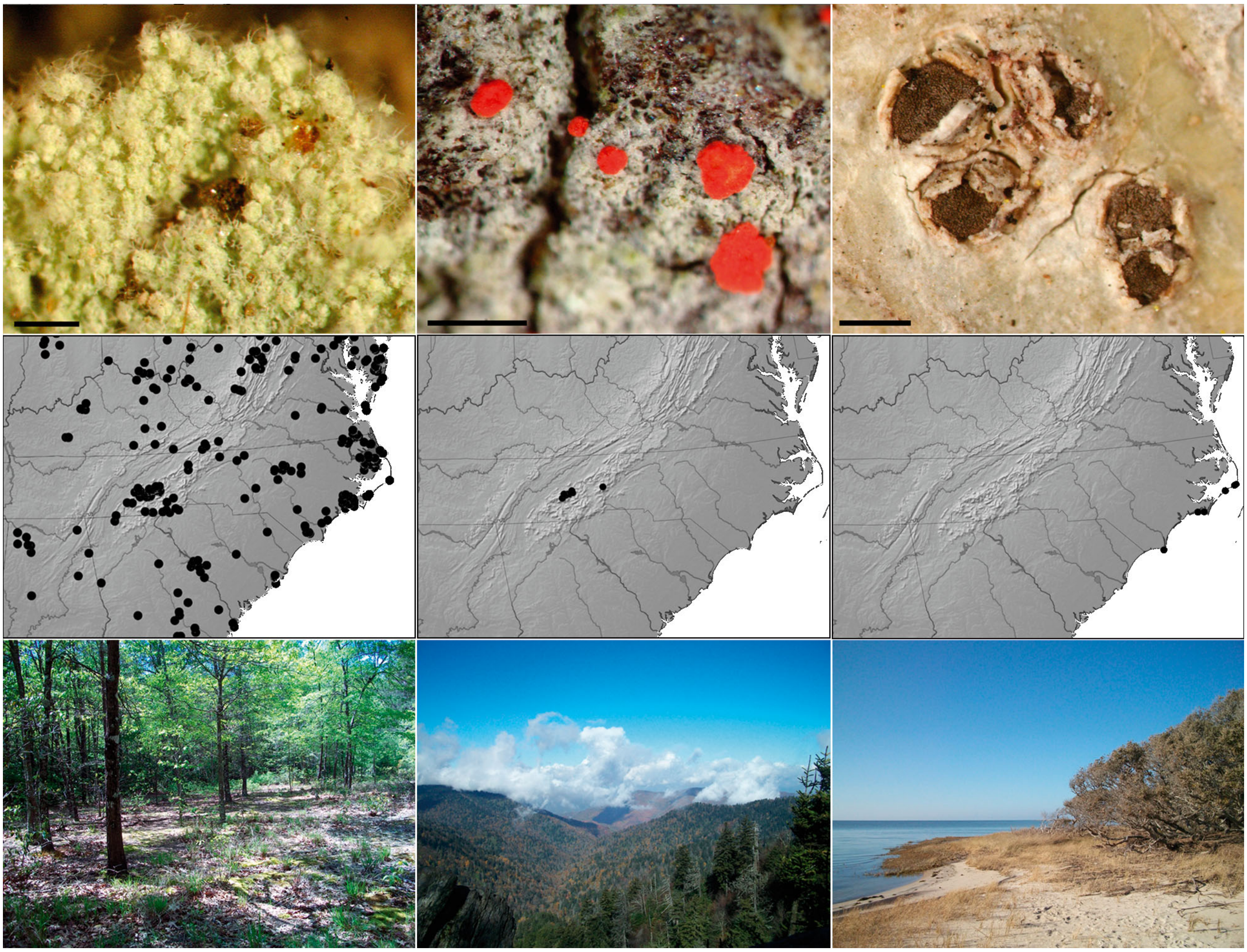

Fig. 2. Comparison of 3 well-studied lichens (top), and their geographic distributions (middle) and habitats (bottom). Left: *Lepraria finkii* is common and widespread throughout eastern North America, occurs in a diversity of forested habitats, and is not threatened. Center: *Arthonia kermesina* is narrowly endemic to the southern Appalachian Mountains, occurs only on mature *Picea* in old-growth forests, and is endangered by many factors (climate change, habitat loss, invasive species, and pollution). Right: *Phaeographis oricola* is narrowly endemic to the Carolinian Barrier Islands, occurs only in mature maritime forests, and is endangered by many factors (sea-level rise, habitat loss/fragmentation, and pollution). All photographs by J. C. Lendemer; distribution maps are based on verified voucher specimens deposited at NY (New York Botanical Garden herbarium). Scale bars in top panels = 0.5 mm

from a landscape perspective, a conservation viewpoint that is widely applied to other groups of organisms (e.g. Pilz & Molina 1996, Pilz et al. 2007).

An extension of the notion of fungi as 'unknown and unknowable' is the application of the 'everything is everywhere' hypothesis. This hypothesis states that the distributions of organisms with propagules smaller than a certain threshold are not limited by dispersal ability, and instead are limited only by the availability of abiotically and biotically suitable habitat (O'Malley 2007). This hypothesis has been widely applied to fungi; thus, it is assumed that suitable substrates found in climatically similar regions will share similar fungal communities. This assumption leads to unending perceived uncertainty about the distribution of species, culminating in the assumption that fungal species can neither have narrowly endemic ranges nor follow biogeographic patterns such as those documented for other organismal groups. The result of accepting the 'everything is everywhere' hypothesis, despite ample evidence that it does not apply to fungi, translates to an inability to produce conservation assessments because the distributions of species are assumed to be incomplete or unknown when data support their endemism or rarity. Moving past the paradigm of 'everything is everywhere' is essential if fungal conservation is to progress.

## TOWARD FUNGAL CONSERVATION: ADVANCING A NARRATIVE

The impasse with respect to fungal conservation in the USA largely stems from the continued perpetuation of the narrative that fungi are unknown and unknowable. This has fostered an environment where funding sources and the media focus on projects illustrating that fungal diversity is far from being well documented or documentable. Shifting this narrative to both emphasize and capitalize on the wealth of good, reliable data that are available is the first step toward improving fungal conservation in the USA. It is certainly true that fungi are incompletely known, but the same is true for all groups of organisms that are the active focus of conservation efforts.

Thus, it is imperative that mycologists draw attention to, and educate others about, the many success stories of scientific documentation of biodiversity and subsequent on-the-ground potential for conservation. This means not sensationalizing stories of extreme new species discovery and cases of purported cryptic speciation where researchers despair at their inability to distinguish species, as these are the minority of studies on fungal biodiversity. This is analogous to disproportionately emphasizing the small number of studies that refute the near consensus on climate change. Focusing on such cases does have shock value and captures attention. Nonetheless, they only serve to reinforce the false impression that researchers who study fungi are decades behind their counterparts in other fields in terms of understanding species and their conservation needs.

## TOWARD FUNGAL CONSERVATION: ADVANCING AWARENESS

Increasing the baseline of fungal knowledge for those outside the mycological community is a crucial step towards incorporating fungi as integral components of conservation planning. This would lead to an increase in the value society places on these organisms, as well as an increase on the value and merit associated with specialized knowledge about them. A broader public awareness of the value of fungi would lift the universal veil of fungal blindness that enshrouds much of the USA and ensure that everyone from policy-makers to land managers and teachers to farmers no longer see fungi as strange, alien organisms of little or no ecological importance, when they see them at all.

Investments in the development and implementation of diverse education efforts about fungi, comparable to those for plants and animals, are immediately needed. Such efforts must span all available audiences from the earliest grades to undergraduate curricula to established adults in academic and policy positions. Well-crafted informational campaigns aimed at the general public would be particularly impactful. Fungi are beautiful and remarkable organisms that are important members of American ecosystems and also excellent indicators of ecosystem health. Many fungi are also threatened or endangered. It is time that these facts are coherently articulated in a coordinated effort to educate society. The more people who are aware of the importance and diversity of fungi, the greater the chance to establish parity with plants and animals in the sphere of conservation.

## TOWARD FUNGAL CONSERVATION: ADVANCING INFRASTRUCTURE

In addition to improving the baseline level of fungal knowledge in the USA, there is a complementary need to enhance intellectual infrastructure by training a diversity of professionals in mycology. Although fungi are better understood than is generally perceived, there are many areas of research that require urgent study but remain substantively underfunded and understaffed. These avenues of research include large biodiversity inventories and assessments, studies of ecology and population genetics, description of previously unknown species, and development of effective taxon-specific conservation or mitigation practices.

While the broad need for training and research outlined above is clear, it is equally imperative to support the evaluation and accessibility of existing data so that species can be assigned ranks that accurately reflect their conservation status. Such data take many forms, from published studies to physical vouchers stored in herbaria. These resources are the physical infrastructure upon which conservation assessments are based. Although knowledge of fungal diversity in the USA is far from complete, the wealth and breadth of available data are substantial. This is evidenced by the establishment of centralized resources for information pertaining to macrofungi (MCC 2014) and lichens (CNALH 2014), both of which were initially supported by grants from the US National Science Foundation. The quality of these resources, however, must be maintained and improved to assure that species assessments are robust and accurate.

The only way to safeguard the reliability of data, and the assessments that draw on them, is to contract, employ, and consult experts in fungal biodiversity. NHPs, state departments of natural resources, and federal agencies charged with biological resource management need to devote resources to hiring specialists in mycology, as is standard for wildlife and vascular plants. While the number of wildlife biologists and botanists employed in these areas is often insufficient, similar positions for mycologists are virtually nonexistent.

The use of a default status of 'Incomplete Distribution Data' was a logical first step taken to bring attention to the need to include fungi in conservation. Nonetheless, simply having a list of names of data-deficient fungi that may be threatened and endangered does not translate into meaningful action. Meaningful action must take a diversity of forms, from ranking threats of species and highlighting specific additional research areas to developing mechanisms for training specialists and securing targeted funds.

## TOWARD FUNGAL CONSERVATION: ADVANCING COMMUNICATION

We recognize that the courses of action suggested herein will require a concerted effort by many parties. As such, the most important step toward fungal conservation in the USA is to advance communication among the involved stakeholders. Ranking and listing of threatened or endangered species cannot occur in a vacuum, rather it must be conducted in full consultation with specialists who have extensive detailed knowledge of the organisms involved (Minter 2011). Concurrently, mycologists must be open to an exchange of ideas with those responsible for development and implementation of conservation policy. Meetings bringing environmental policy-makers, land managers, and mycologists together to commence communication and formulating action items for all parties would be a logical first step. Specialists working on fungi must recognize that, in the face of the challenges posed at the beginning of the 21st century, it is time to participate actively and materially in the conservation dialogue.

## CONCLUSION

Expanding the conservation paradigm in the USA to include fungi is imperative at all levels of government and society to maintain functioning ecosystems and sources of novel bioactive compounds. Management policies and conservation strategies developed without the consideration of fungi and other biologically diverse understudied groups remain incomplete and potentially less effective. The institutions responsible for the management and conservation of natural resources in the USA must be held accountable for fungal conservation, as they are for the conservation of plants and animals. While these conclusions are not new, they are increasingly urgent in the face of the current biodiversity crisis and other global phenomena that challenge the continued existence of ecosystems and species (IPCC 2014).

The knowledge and data required to move effective conservation of fungi forward at species and landscape scales are available in the USA. The largest barriers to the utilization of this knowledge in conservation planning are the perception of their inscrutability, the small number of trained professions in the field, and the near absence of fungi in laws relating to conservation. Although truly data-deficient areas and species do exist, these are identifiable and could be remedied pending support of a physical and intellectual infrastructure. Hiring of specialists with knowledge of fungi must be prioritized to vet and edit existing biodiversity data and conservation assessments that land managers rely on. Broad educational outreach must also be undertaken to increase the baseline knowledge of the breadth and value of fungal diversity in those outside of the mycological community. Concurrently, within the mycological community, we must also seriously work towards these goals, presenting a robust and unified narrative with clearly articulated priorities.

*Supporting information*. The authors are solely responsible for the content and functionality of Supplement 1 and 2. Queries (other than absence of the material) should be directed to the corresponding author.

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