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***Research Article***

# Conservation of Abundance: How Fungi can Contribute to Rethinking Conservation

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**Abstract**

Mainstream biodiversity conservation continues to emphasise the rapid disappearance of charismatic megafauna. Fungi are ignored, partially because many are invisible. However, their conservation is of growing concern because their decline signals a decrease in overall biodiversity and losses in ecosystem integrity and function. Social science engagement with microbes is of growing interest because the diverse characteristics of fungal bodies create new entry points for conservation. Using data collected over three years from literature review, lab ethnography, and interviews, this paper develops two new concepts intended to operate at the intersection of these discussions. A review of the fungal conservation literature finds mainstream species conservation an ill fit for fungi. Drawing from the literature on ecosystem function and conservation biopolitics, I introduce the term 'functional collectives' to reframe the role of fungi in nature through a focus on fungal bodies. Acknowledging the extraordinary diversity of fungi and their relative unknowability, I further introduce the concept of 'conservation of abundance'. A focus on abundance rather than scarcity meets the needs expressed by fungal conservationists for habitat protection and conservation based on available knowledge. Both concepts align with the biophysical realities of fungi while also answering growing calls within social conservation for conviviality and care.

**Keywords:** microbes, ecosystem function, biopolitics, microbial labour, more-than-human

## INTRODUCTION

Conceptual work at the natural-social science interface on conservation is epistemologically challenging because it diverges from conventional ways of knowing, asking scholars on both 'sides' to expand their perspectives. Social scientists researching conservation have made multiple attempts to argue this case directly to conservation biologists (Mascia et al. 2003; Sandbrook et al. 2013), more recently "urg[ing] the conservation community to move beyond superficial engagement with the conservation social sciences," (Bennett et al. 2016: 56). However, it could also be said that critical social science research on conservation has a similarly limited engagement with natural sciences, focusing on power dynamics in a range of areas, such as the power of capitalism and neoliberalism in conservation (Heyden and Robbins 2005; Büscher and Fletcher 2020); the power of the state in defining land tenure and environmental actors through the creation and management of protected areas (Agrawal 2005; West 2006; Weldemichel 2021); the power of communities in species governance (Tsing et al. 2005) and the power of 'western' science in conservation management (Agrawal 2002; Barron et al. 2015). Sandbrook et al. (2013) distinguish between social research for conservation, such as those papers making a case for the inclusion of social sciences, and social research on conservation, such as those focusing on power dynamics.

Research 'for' and 'on' conservation can make valuable contributions to how to do conservation better, but do not necessarily push the field of conservation forward theoretically or conceptually. Concepts such as social nature (Demeritt 1998; Castree 2001; Demeritt 2001) and

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socioecological transformations (Braun 2015; Hawkins et al. 2015) have made way for novel interdisciplinary interventions. For example, Mansfield et al.'s (2015) work on socioecological forest types proposes a new classification system for hardwood forests occurring in the coalfields of Appalachian Ohio. Rather than defining forests in this heavily disturbed area solely on their species complexes and ecology, they create a typology of forest types, including silvicultural forests, historic forests, livelihood forests, and privacy forests. These types incorporate ecological aspects with human actors and management actions. The typology shifts the premise for forest management from nature-based towards one which attends to nature and justice to protect social natures that benefit both humans and earth others. Barron et al. (2015) tackle the challenges of interdisciplinary work on nomenclature, where scientific names for species are often considered the correct, true names and those originating in indigenous or local knowledge are classified as 'folk taxonomies or ethnobotanical names. They engage the concept of performative method to focus on the culture and meaning embedded in both local and scientific name creation and use. They argue that acknowledging the context and meanings inherent in nomenclature "reframes knowledge production around shared interests in environmental questions and challenges" (Barron et al. 2015: 640). Both examples provide new conservation and resource management tools if those practising are able to access and adapt with them.

Similarly attempting to work 'with/in' conservation, this paper introduces two new concepts drawing insights from molecular ecology, genetics, and critical social theory. The first concept, 'functional collectives', is informed by the emphasis on function in ecology (Hooper et al. 2005), as interpreted through conservation biopolitics to be about fungal bodies and with an interest in their collective labour (Barron and Hess 2020). The second concept, 'conservation of abundance' is inspired by a need to think differently about conservation of fungi, which can be expanded upon for conservation of other organisms. I use the mega-diverse functional group of fungi as an entry point into this reconceptualisation because their conservation is increasingly of interest in the natural sciences (Blackwell 2011; Heilmann-Clausen et al. 2015; Antonelli et al. 2020) and as an emerging field there is an opening for change. From a social perspective, concerns of scarcity and anxiety as drivers of conservation institutions (Braun 2011; Robbins and Moore 2013) operate differently when applied to fungi, creating a novel entry point into conservation discourse.

This research article proceeds as follows. The use of biopolitical theory in conservation social science is distinct from other uses, requiring a bit of explanation and review to demonstrate its utility in the current analysis. It is followed by a methodology section explaining my ethnographic lab-studies-like fieldwork in a mycology lab at Harvard University over two years. The data supports the idea that fungi require a new form of conservation, one which decentres measurement and organisation of living beings into discrete groups or populations. Rather than focusing solely on their identities, I use biopolitical theory to recognise the work fungi do together in ecosystems. In other words, examining collective work (Barron and Hess 2020) in ecosystem functioning enables the idea of 'functional collectives'. These collectives represent an abundance of life humans live with, in a diversity of relations. 'Conservation of abundance' is therefore meant to capture the call from scientists who work with fungi (fungal scientists) to protect the massive diversity of fungi because they deserve and require protection even though they are abundant, and also because of the abundant surplus value they create for and with humans (Barua 2019). In these respects, the conservation of abundance concept is consistent with the conservation social science literature on conviviality and care, which reframes conservation as celebrating and caring for nature (Büscher and Fletcher 2020). For fungi and other micro-organisms, this interdisciplinary reformulation of fungal conservation as a conservation of abundance rather than of conservation to combat scarcity exemplifies social science with/in conservation because it draws conceptually from both the social and natural sciences.

## BIOPOLITICS FOR CONSERVATION

Conservation is a social institution with rules and norms of engagement, as much as it is an applied science. Lorimer (2012) summarises the sociopolitical history by calling out biodiversity as a "neologism that was coined at the end of the 1980s by architects of conservation biology—a self-declared 'crisis discipline' (Soule 1985) that sought to catalyse public support and provide the scientific expertise for biodiversity conservation (Takacs 1996: 2)". As a scientific concept biodiversity was broadened to focus across trophic levels and include ecosystems, but in practice species remain the focus with rarity and extinction risk as the key reference points in scientific research (IUCN 2010; Díaz et al. 2019; Fromentin et al. 2022).

Species-centred science communication and outreach motivate individuals, the public, and private sectors towards protection and responsible engagement with the natural world. The International Union for the Conservation of Nature (IUCN), for example, is an internationally recognised organisation whose 'most recognisable product' (Campbell 2012) is the Red List of Threatened Species (see iucnredlist.org). Recent work on the global state of biodiversity also focused on species: out of thousands of pages, the main headline from the 2019 Global Assessment of the Intergovernmental Panel for Biodiversity and Ecosystem Services (IPBES) was that "humans are driving 1 million species to extinction" (Tollefson 2019). The main headline from the recently released Assessment on the Sustainable Use of Wild Species similarly pointed out that humans use and rely on over 50,000 wild species (Fromentin et al. 2022).

Species-centric conservation emphasises the individual bodies of species of concern, creating an entry point for biopolitical analysis. The use of biopolitical theory has been increasing in geography since the 1990s (Rutherford and Rutherford 2013a), and in critical conservation scholarship

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since the 2010s (Biermann and Anderson 2017). For critical conservation scholars, biopolitics provides an analytical lens through which to consider the technologies, values and governance systems applied in conservation science and practice as a series of relations among humans and non-human bodies.

Biopolitics is most clearly defined as the means by which a group of living beings is measured in order to be governed. In standard conservation practice, these measurements are done using the methods of population and conservation biology. Biermann and Anderson (2017: 4) point to the Linnean taxonomic classification system as one technique through which "non-human life is made calculable and thus governable." They also identify the importance of visibility to biopolitical management: "a biopolitical approach to endangered species management extends the focus beyond formal policies and regulatory norms to consider the specific calculative techniques and assumptions that first make endangerment visible and then summon forth solutions that appear both obvious and neutral," (Biermann and Anderson 2017: 4). They argue this neutralisation of values hides the fact that certain species become more valuable at the expense of other species. They conclude that "this notion that conservation is biopolitical—that its foundational understandings and assumptions produce valuations of life that foster some lives while diminishing others—is most effective as a starting point rather than an endpoint for research" (Biermann and Anderson 2017: 10).

Biermann and Anderson (2017) focus on the size of the population and habitat in relation to the perceived risk of extinction; I adapt their argument to make a point about the size of individual bodies and their role in maintaining established conservation practices. Elephants, for example, are an archetypal conservation animal (Lorimer 2010) and are very visible in multiple ways. They are charismatic megafauna and keystone species. The bodies of elephants are indicator bodies for threats to natural habitats, threats to human livelihoods, and justifications for certain forms of action (Lorimer 2010).

Thompson (2004) writes about the co-production of the African elephant and the Convention on International Trade in Endangered Species (CITES) as a case study for an analysis of the co-production of species and governance. She explores the interconnections among data, scientists, countries, CITES, the IUCN, and the counting of African elephants. Efforts resulted in the creation of a separate Southern African elephant population, which then required independent governance under CITES. The counting initiative she reports upon was, in part, 'in response to the threat of a reduction in threat status'. The threat to policy brought forces together to assert regional differentiation based on specific characteristics and traits that "indigenised" (Thompson 2004: 83) the elephants of southern Africa. In biopolitical terms, elephant bodies were more closely connected to specific places to remake species identities and maintain established conservation governance.

Shifts in the management of species bodies through population-level interventions (Biermann and Anderson 2017), in the case of elephants, facilitated more place-based and focused management, a likely benefit for the longevity of the genus. However, this example also highlights the attention given to the specific species and how those efforts reinforced existing institutional norms of conservation. An analysis of the political repercussions of the taxonomic classification of Preble's meadow jumping mouse *Zapus hudsonius preblei* (Crifasi 2007) similarly highlights the role of species bodies and the politics of nomenclature (Bowker and Star 1999) in management and conservation. Mice occupy space very differently than elephants, but their visible bodies were still used to affect conservation practice and policy, in this case, with regard to the American Endangered Species Act.

Rutherford and Rutherford (2013b) synthesise the work of Judith Butler to suggest the basis for an 'affirmative biopolitics' as one in which awareness and attention to how life is ordered enables us to ask, perhaps even to choose, our own positionality in relation to the power of species-centric biodiversity conservation. Drawing from geographical and STS scholarship, they extend this to the non-human to suggest that rather than being constrained by choices about who lives or dies (identified as a key aspect of biopolitics), an affirmative biopolitics considers who and what can claim purchase to care. This is not only socially constructed but open to reinterpretations offering more complex, co-produced possibilities for who can claim a right to be and why (Rutherford and Rutherford 2013b).

## METHODOLOGY

The data presented here are part of a two-year NSF-funded postdoctoral fellowship at Harvard University in the Evolutionary and Organismic Biology department to study the effects of genomics and metagenomics on phylogenetics and the classification of fungi (2011-2013). The project grew out of previous work on the importance of the species concept in fungal management and decision-making (Barron and Emery 2012; Barron et al. 2015). This interest subsequently expanded to include questions about how rapidly changing technologies in microbiology were affecting conservation more broadly. From an evolutionary biology perspective, the focus on fungi is key because metagenomics radically changes how fungi are understood and researched (Hibbett et al. 2016), and how they can be studied for conservation (Dahlberg and Mueller 2011). From a critical theory perspective, the idea that invisible and relatively unknown organisms are suddenly made legible and can therefore become subjects/objects of conservation (Barron 2010) creates a unique opening for social and institutional analysis.

Data were collected following an ethnographic research design that included interviews and participant observation (Creswell 2003; Hay and Cope 2021) in the Pringle Lab, and interviews with other fungi researchers in nearby laboratories at Harvard and neighbouring universities. Over two years as a member of the lab, I studied researchers' processes, lab dynamics, events, and lab members' connections to the broader

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scientific communities in which they participated. I had a desk in the main room with the Ph.D. students and postdoctoral researchers; our office was inside the laboratory itself, so I also regularly observed people working in the lab on various technical tasks. I attended weekly lab meetings and department lectures, socialised with my lab-mates, and was generally a part of the group. Outside of 'our' lab, I was perceived as a 'regular' member of the Pringle lab, not a visiting researcher. This may be in part because I joined the group within the context of a different project.

Participant observation also extended to event ethnography at mycology conferences, where I presented my own research, attended the presentations of my lab-mates and those related to both fungi conservation and lab-related research themes. As part of this project I attended the XVI Congress of European Mycologists in 2011, the European Congress of Conservation Biology in 2012, and the Mycological Society of America meeting in 2012. The current research article draws on data from across these methods.

A total of 13 interviews were conducted over a period of approximately 14 months. Interviews ranged from one to two hours. Questions were grouped into five categories: 1) introductory, 2) genetics and metagenomics, 3) species, 4) fungal biodiversity, conservation science and conservation policies, and 5) general science and the course of one's own work. Each category contained six questions except 4, which had nine. Questions were designed to explore how different participants considered these concepts, scholarly debates and the role of the public in relation to their research on fungi and advanced technologies. An additional 21 people participated in the study through participant observation or answering questionnaires at conferences; results from the questionnaires are not included in the current analysis.

Audio recordings of interviews were transcribed in their entirety using WAVPedal software. Field notes and photographs supplement the audio recordings and were analysed to provide context. Data were analysed in Atlas.ti 6 for Windows (2011) using both descriptive and analytical codes (Hay and Cope 2021) in the following code families: biodiversity, conservation, lab studies, data, demography, emotions and personal, political ecology issues, mycology as a discipline, species and function, and taxonomy and nomenclature. The current research article draws on the analyses of codes from the first three code families listed here. To protect identity, participants were anonymised according to their workplace, their type of participation in the project, participant number, and research concentration. For ease of reading, direct quotes from the interviews presented below, include participant number and research concentration only.

Regarding researcher positionality, in many ways, I was very similar to my research participants: a group of highly educated, majority female, majority white, people of American/European descent from middle and upper-middle-class backgrounds. Especially having started working in the lab group before this project, it was hard at times to not 'go native' as Latour and Woolgar (1986) caution against. However, it could also be said that this insider status allowed me to mobilise various aspects of shared identities and experiences with the study participants to negotiate research relationships, establish rapport, and gain access (Hay and Cope 2021). Often there were times when the project took on the feeling of a group project, where we sat and tried to figure out what different people think about conservation. The following literature review on the value and importance of fungal conservation is a direct result of these conversations, shaped as it was by the perspectives and literature provided by my lab-mates and thus deemed part of the results from lab ethnography. I maintain it as a literature review rather than a discourse analysis because it was not originally structured according to discourse analysis methodology.

My positionality and reflexive process were also affected by my active participation in a second research group at Harvard during the course of this project, the Science and Technology Studies (STS) programme at the Kennedy School. It was through participation in this second group that I was able to develop and maintain some analytical distance during the research process. As part of the study design, both groups met on two occasions to foster multidisciplinary communication. These events made a strong impression on all attendees, and subsequently I was recognised as more of an interdisciplinary scholar than I had previously been in either group.

## RESULTS: FUNGI SCIENTISTS ON FUNGI CONSERVATION

### From ecosystem function to functional collectives: a literature review

This section blends a scientific literature review with reflections on fungi conservation from ethnography and interviews. As such, I consider it a reflexive literature review resulting from concurrently participating in and studying the developing field of fungal conservation.

Mycologists maintain that fungi are important because they are cosmopolitan, fundamental to every ecosystem, and provide primary support to plants and animals (Dahlberg et al. 2010; Halme et al. 2012). They are central to sustainable land use to maintain wild and protected areas, as well as for agriculture and timber (Heilmann-Clausen et al. 2015). Fungi provide ecosystem services in every category identified in the Millennium Ecosystem Assessment (2005): provisioning food for people and animals, regulation of earth's biogeochemical cycles, support for ecosystems by playing key roles in decomposition, weathering, soil formation and maintenance, and culturally through culinary, religious and medicinal uses (Pringle et al. 2011). The topic of ecosystem services came up in four interviews, always in relation to the importance of fungi in the ecosystem coupled with some reference to social or economic aspects immediately identified as outside the person's comfort zone of expertise and, therefore, not discussed further.

The need for fungi conservation was first suggested through a series of papers published on observed declines in mycorrhizal

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species of fungi in the Netherlands in the 1980s, due in large part to air pollution and acid rain. Mycorrhizal fungi, especially, play critical roles in all ecosystems by facilitating water and nutrient exchange for trees and other plants, and aiding plants with resistance to insects and toxins (Arnolds 1989a,b; 1991). Declining fungal populations, Arnolds argued, were an under-documented threat to entire ecosystems.

Ongoing efforts within the mycological community (mostly in Europe) (Barron 2011) resulted in the first symposium on fungi at the European Congress of Conservation Biology in 2012. Following the symposium (which I co-organised), we published a paper outlining the need for fungal conservation and greater awareness of its importance among policy-makers:

> So far fungi have received limited emphasis in conservation biology (Griffith 2012), except as potential threats to ecosystems, individual species, or species groups (Fisher et al. 2012). Reasons for this neglect are complex but seem related to a general suspicion of fungi in the English-speaking world, their hidden lifestyle and challenging diversity, and a historical classification as an odd division of the Plantae (Minter 2010). We are certain the situation is changing due to an ongoing revolution in methods to obtain data on fungal species and communities and because fungi are the foundation of a variety of ecosystem services (Heilmann-Clausen et al. 2015: 2).

The "ongoing revolution in methods" played a significant role in scientists' ability to engage with fungi in news ways, which resulted in new knowledge of fungal populations and communities that could, in turn, be useful for conservation. It also changed how individual species were identified and known.

At the Pringle Lab I learned how fungal species have been described using different species concepts: morphological, physiological, mating-based, and more recently based on molecular characteristics (e.g., from phylogenies based on barcodes, sets of genes, or genomes) (Taylor et al. 2000; Xu 2020). Due to the variety of fungal bodies, species concepts have been used inconsistently within the fungal kingdom. Macromycetes, which often produce easily visible mushroom structures, have traditionally been classified with morphological approaches that are not applicable to microscopic fungi. Recent estimates suggest the vast majority of diversity in fungi is actually among microscopic organisms (Blackwell 2011), which are primarily embedded in substrates (soil, leaves or decaying wood). Even many macromycetes are mycelial for most of their lifecycle and thus are hidden from view. The inability to identify so many species morphologically explains why the rise of molecular tools has been so significant for this group of organisms.

Fungi are generally highly abundant, but their invisibility makes them particularly difficult to count and identify. Thus, from a mainstream conservation perspective, a major problem with fungi conservation is the challenge in locating and identifying species, and then assessing their population changes over time (Dahlberg and Mueller 2011) in order to determine if they are at risk, since risk is one of the primary criteria for conservation. Fungal biologists identify two additional issues: 1) lack of awareness of the diversity and many benefits of fungi to global biodiversity and human well-being and 2) the need for conservation actions and policies for fungi. Both of these issues were common concerns voiced throughout my time in the Pringle Lab as general truths: in meetings, interviews, and discussions about conservation and are well-documented in the relevant literature (Hawksworth 2003; Dahlberg et al. 2010; Griffith 2012).

Following Arnolds (1989a,b; 1991), mycologists became more focused on introducing fungi into international conservation arenas, especially the IUCN (Arnolds 1991; Moore et al. 2001; Barron 2011; Heilmann-Clausen et al. 2015). The IUCN Red List infrastructure was adapted for fungi (Dahlberg and Mueller 2011), and between 2014 and 2021, the number of fungal species assessed using these criteria rose from two to 425. This move to red list fungi has increased fungal visibility at the IUCN.

The choice by fungal scientists to work within the Red List framework has solidified the centrality of species in fungi conservation. Yet, many fungal scientists discussed how a broad level of separation could further enable the development of different types of fungal conservation, which could in turn enhance the conservation of fungi and microbes (Griffith 2012). Following observed divisions in the scientific literature, one proposed strategy is to separate fungi into three groups: 1) macromycetes (fleshier, larger fungi) and lichens; 2) micromycetes (very small fungi); and 3) uncultured genetic species (known only from DNA fragments). I observed that this division is notably consistent with mycological specialisations into different research areas. The bulk, if not all, of fungi conservation activities have focused on macromycetes and lichens up to this point, unsurprising given these species are most easily found, assessed, and monitored over time by scientists, amateur mycologists, and local experts (Barron et al. 2015). They make up the vast majority of those documented and monitored using the Red List criteria (Senn-Irlet et al. 2007; Dahlberg and Mueller 2011; Heilmann-Clausen et al. 2015). The conservation of these species also follows similar biopolitical logics as those presented above: organisms are measured and assessed in order to be governed in accordance with Red List indicators (field notes from mycological conferences in 2011 and 2012). It should be noted that except for lichens and some shelf mushrooms, most macromycetes are also relatively invisible except when they are fruiting, as the mycelia mostly grow underground or in enclosed substrates such as logs.

Uncultured genetic species and micromycetes are always invisible but, like their larger cousins, play major roles in ecosystem functioning processes, from animal or plant symbionts to biogeochemical cycling to decomposition. These groups have the most undocumented fungal diversity. Uncultured genetic species may not be microscopic, but without culturing them there is no way to know, and these species are being discovered at such high rates that the likelihood of 'growing them up' to an observable size is low

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(Hibbett et al. 2016). Thus conceptually, micromycetes and uncultured genetic species are collectively referred to here as 'micromycetes'.

Biopolitical theory enables the framing of micromycetes as invisible bodies and populations (of unknown size and location), which become visible through the ways in which they interact with and are governed by people and institutions. In the same ways that the science of demography was crucial for Foucault's biopolitics (Rutherford and Rutherford 2013a), genomics and metagenomics play a critical role in enabling a biopolitics of fungi. This enables a shift from ecosystem function towards functional collectives because in making micromycetes visible, focus shifts onto fungal agency and labour.

As I observed in the Pringle Lab, knowing and measuring invisible fungal bodies is a rapidly developing field. Metabarcoding and metagenomics, where whole communities of organisms are measured and identified using Next-Generation Sequencing, has exponentially grown in recent years, leading to vast amounts of data regarding which microbial species exist and where they are located. With this technology, scientists can use DNA fragments to confirm the presence of microscopic organisms across different habitats and ecosystems. However, many drawbacks still exist. Paramount for conservation, this type of sequencing measures relative and not total abundances, so population numbers cannot be properly quantified. Without knowledge of population size, one must interpret changes in relative abundance based on known effects. For example, in a freshwater lake, it is not possible to accurately estimate the total number of cyanobacteria, but when there is a massive algal bloom it is possible to posit changes in the aquatic environment that have affected the population size. There are issues, also, with proper identification. Microbes are only able to be taxonomically identified if the relevant (or closely related) DNA sequences already exist in databases. Thus, truly knowing the numbers and identities of these invisible species is currently out of reach (Blackwell 2011; Louca et al. 2019).

## Habitat protection for the abundant unknown: conversations with scientists

Almost regardless of the strength of the science, fungal red lists and conservation remain a niche area for two reasons: First, macromycetes are not charismatic or cuddly, micromycetes are literally invisible to people. Mycologists recognise this:

> Not being able to see things is an important point. You can see macrofungi when their fruit bodies come. It's quite a hard concept, isn't it, for lots of people to know that there are things that are invisible things out there really keeping this planet going and we can't see them. (Field interviews, 17Ecology, 2012).

> All of the conservation strategies we have for anything are based on being able to see whether it's there and knowing how [human actions] affect population size. I suppose you could do that with sequences too, couldn't you? It just happens that they're invisible, so you wouldn't do your conservation surveys the same way; you'd have to do it molecularly. (Field interviews, 13Mycology, 2012).

These researchers acknowledge the challenges of trying to conserve invisible organisms, which they themselves only recently became aware of using metagenomics. For them the technology makes fungal bodies real and, therefore, worthy of conservation, but this is much harder for the general public.

Possibly abundant, physically invisible, and almost impossible to count and measure, Latour (1986) would suggest that bodiless organisms have biopolitical power through the novelty of the technologies of engagement used in their discovery, representation and visualisation. DNA becomes visible, measurable and powerful through the use of DNA electrophoresis. Genetic sequences in the environment become more powerful through metagenomics, a way to uncover thousands of unique (but still invisible) sequences simultaneously:

> Sampling data using modern [high throughput sequencing] methods, definitely you can make the public aware about how much diversity could be present in a certain ecosystem but that's all sequences, you don't have something that people can actually visualise, can understand. (Field interviews, 16Mycology, 2012).

The novelty stems from a rapid discovery rate, but how to document those species is undecided and lacks uniformity. New species are being discovered so quickly that they are not named following traditional Linnean classification (Hibbett et al. 2011). Microbiologists are proposing alternatives: for example, *SeqCode: Path forward for naming the uncultivated* (https://www.isme-microbes.org/seqcode-initiative) is a new initiative for naming uncultivated bacteria and archaea. It remains an active area of discussion and debate.

The second challenge for the conservation of micromycetes is that with no visible bodies there is nothing to count, nothing to directly manage, and nothing to control. Bodiless entities in the soil, air and water are as abstract as ozone or carbon. Macromycetes are more manageable due to the consistent or periodic appearance of fruiting bodies. Micromycetes must be managed another way, and a majority of the scientists in this study agreed that it was to focus on habitat protection:

> The best way to conserve fungi is to conserve the widest variety of habitats that fungi grow in, if that's possible. (Field interviews, 14Mycology 2012).

> I guess in my ideal world we would say there is an inherent benefit to preserving certain habitats, and letting them be dynamic, interdependent communities that we're trying not to impact too much by our activities. (Field interviews, 9Biology 2012).

Reconceptualising microbial conservation in relation to habitats and ecosystems, for these researchers, addresses the lack of awareness by scientists and the public alike, and the lack of data on fungal species. It circumvents the complexity of their biology in favour of their ecosystem function. Importantly, in the second quote fungi are recognised as dynamic members of interdependent communities. In the following quote it is clear

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that an appreciation of fungi and microbes is not just for nature preservation, it is for self-preservation as well:

> I want to be able to give people this new perspective of how we're interconnected with our world and how to care more about it as a whole, and how we effect other things, to be better able to live harmoniously with the things around us. I think having an understanding of microbes really ties into that because we have so many of them in our bodies, so it's easier for us to relate to how they affect other ecosystems because if you think about our human ecosystem, we have all these communities of organisms. (Field interviews, 3Biology, 2012).

In this quote the desire to "live harmoniously with the things around us" is linked to an awareness to live more harmoniously with the microbes inside us as well. To care for them is to care for ourselves, and users of probiotics know we need billions. This is an affirmative biopolitics of conservation because it is about what and who can claim purchase to care; in this case it is truly a conservation of abundance as care for self. If fungi cannot claim that care with visible bodies, they can claim it through their roles, their collective work, in ecosystem function—extended here to include human microbiomes—such that the lines become blurred between self care and ecosystem care.

## FUNCTIONAL COLLECTIVES AND THE CONSERVATION OF ABUNDANCE

A biopolitical analysis of fungi conservation shows that it cannot function like other areas of conservation because fungal bodies are radically different from those of plants and animals, for whom conservation was designed by scientists and management agencies alike. Maintaining ecosystem function through habitat preservation is one of the arguments made for the conservation of flora and fauna, but for many fungi it is currently the only argument. Biermann and Anderson (2017) point to Linnean classification as a technique to make non-human life governable. However, as is clear in the literature review, new species of fungi are no longer being named according to this system. Biermann and Anderson identify the importance of visibility for management, but many fungi are not visible for most or all of their lives. They refer to the role of value in weighing and measuring what should and should not be conserved; but scientists in this study all discussed the reputation of fungi as bringers of disease, decay, or death—making them seemingly unworthy of conservation.

Fungal scientists are clearly concerned that if not actively derided, the lack of awareness of the importance of fungi for ecosystem function always remains in the background. What is clear throughout the data is that they are very aware of the important role that fungi play in the environment, which they call function and I call work. Renaming function as work draws attention to the "affective dimensions of nonhuman labour" (Barua 2019: 664) to co-constitute conservation. We are surrounded by the results of this collective work, framed as ecosystems function, due to the result of these 'functional collectives', which are not limited to micromycetes or fungi. Indeed, other animals, plants, and humans are part of what makes various collectives function.

The semantic shift from function to the functional collective is consistent across ecological and health research, where groups of related organisms are often discussed as assemblages (Stroud et al. 2015). Human geography and anthropology research similarly use the concept of assemblages in terms of relationality (Galvin 2018; Krzywoszynska 2020), and 'living with'. Tsing (2015), whose work like that of Barua (2019) focuses more on political economies of human-non-human relations, finds the concept of assemblage useful to examine and unpack the political and economic dimensions of human and more-than-human lifeways in relation to mushroom gathering. Barron and Hess (2020) focus more specifically on human and fungal labour using diverse economies framing informed by assemblage thinking. My concern in this paper with labour is less focused on exploitation and more on the idea that recognition of collective work builds relational value (Chan et al. 2016), which, in turn, motivates new forms of conservation.

In the Anthropocene, conservation can be understood as 'claiming a right to be' in a world subject to human choices. Finding value in nature, specifically by relating with it, is further developed for conservation through the concepts of convivial conservation and green care practices. Using the centrality of bodies now identified and a shift towards care enabled through an affirmative biopolitical interpretation of habitat management, convivial conservation (Büscher and Fletcher 2020) and green care practices (Moriggi et al. 2020) allow for the further prioritisation of relationality, interdependence, and the need to pay more attention to non-human life by living with, caring for, and celebrating nature.

Care, reciprocity, and mutual learning with and among people and nature form an integrative framework on which to build conservation and sustainability praxis and community, bringing relationality and care to the forefront of socionatures. By focusing on place-based sustainability Moriggi et al. (2020) break away from the species focus in their conservation work, moving towards what Turnhout et al. (2013: 1) call 'living with' biodiversity. Engaging specifically with the literature on green care and employing in-depth participatory action research, Moriggi et al. bring to the foreground ways in which "a care lens sheds light on practitioners' moral agency and its sustainability potential." They engage people already living with nature in ways that foster abundant well-being and social inclusion (Moriggi et al. 2020). Like Bücher and Fletcher (2020), the vision for future conservation is hopeful and relational. It is premised on widespread engagement and action with and in nature rather than regulatory and private management.

The uniqueness of fungi conservation is made visible through this analysis of the relationship between populations, governance, scale, and power. The empirical data suggest overall habitat or ecosystem conservation as one possible alternative, but this allows for rather than affirms a place for

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microfungi (and by extension other microbes and diverse lifeforms) because their bodies are microscopic, and their populations somewhat abstract and therefore difficult to govern. Affirming the value of fungi in conservation rather than tolerating it is critical for a more holistic understanding of the work required for sustainable socionatural futures. A conservation of abundance, then, is about consideration and care at multiple levels, from the self and our own microbiomes, to the larger communities, ecosystems and biomes in which we live. It brings together, rather than separates, different populations of organisms across scales and species.

The inherent complexity in developing a conservation of abundance is that it conflicts with the foundational elements of contemporary conservation: measuring and governing populations, and controlling human behavior vis-à-vis nature and natural resources; what Biermann and Anderson (2017: 5) call "managing endangerment." Transitioning from thinking about populations of plants, animals and fungi in terms of the need to protect their bodies to thinking about them in terms of the work they do collectively highlights the agency of the organisms and makes it easier to imagine our lives with them, rather than as their caretakers. It exemplifies the 'living with' way of approaching socionatural relations increasingly articulated in the social sciences while also engaging actively with the natural science concept of ecosystem function in a new way.

## CONCLUSION

Empirically, this research article was inspired by the co-occurance of the troubling of the species concept in the natural (Hibbett and Taylor 2013; Hibbett et al. 2016) and social (Thompson 2004; Crifasi 2007; Barron 2010) sciences. In the natural sciences and specifically in ecological genetics, the challenges of rapid changes in the techniques and pace of species identification resulted from the application of polymerase chain reaction (PCR) testing to fungi in the 1990s. This was followed by fungal genome mapping, e-DNA analysis, and the subsequent classification of thousands of species by code only in the 2000s. These events led to a significant destabilisation of scientific fungal nomenclature (Barron et al. 2015), and additional challenges in fungi conservation (Gargano et al. 2021). In the social sciences, questions about what purposes species identification and classification fulfil in society (Bowker and Star 1999), in conservation (Thompson 2004; Barron et al. 2015), and in environmental decision-making and power-sharing (Agrawal 2002; Raymond et al. 2010) all point to the importance of the politics of knowledge production and knowledge circulation vis-à-vis the species concept.

While mainstream conservation is much broader than species protection and biodiversity, I focus on species and the power that species have in reproducing certain forms of conservation science and policy for three reasons. First, despite the expansion of the nature protection debate beyond biodiversity in the mid-2000s (Hooper et al. 2005), concepts such as species richness, keystone species, community composition (which species) and selection effect (how species affect each other) have been and continue to be central to conservation. Second, biodiversity writ large is considered a core value supporting planetary function (Rockstrom et al. 2009). Human uses of species have been deemed a major driver of species loss and decline (Díaz et al. 2019) resulting in the biodiversity crisis. Third, the destabilisation of the species concept in the field of mycology (due to changing technologies) offers new insights into conservation futures using biopolitical theory, which would otherwise not be visible. Despite these novel technological engagements intended to discover, represent and visualise fungal bodies, microfungi remain especially elusive to conservation interventions like counting and population mapping, and therefore do not lend themselves to traditional conservation measures. The concept of functional collectives makes visible their otherwise invisible labour specifically by drawing attention away from species, while the concept of 'conservation of abundance' allows us a different way to imagine human-fungal futures also less tied to the need to individuate.

Turnhout et al.'s (2013: 154) suggestion that we live with biodiversity by "acknowledging a diversity of values, knowledge and framings of biodiversity, fostering a diversity of social-natural relations" is encapsulated by the concept of functional collectives, valuing fungi collectively for their agency in ecosystem function and elevating the need to ensure their protection. Mainstream conservation does not work well for fungi because of their invisibility, but recognising the outcomes of their work as part of functioning ecosystems can work better. It is a massive diversity of fungi that do this work, most of which remain unnamed and unidentified. What I am proposing is that rather than spend the next several decades working out the biology and ecology of all those species, their diversity can be collectively conserved working to conserve abundance rather than solely combat scarcity. Abundance supports the collective work that all species do in ecosystems. Naming the functional collective, rather than maintaining ecosystem function, in turn, supports the need for the conservation of the abundance of labourers. Moreover, developing names for these collectives that recognise the human and nonhuman labour as well as the ecological components, like the re-naming work by Mansfield et al. (2015), animates the necessary abundance for socio-natural futures.

The conservation of abundance is not about denying real threats to biodiversity. It is rather part of acknowledging that focusing only on species in decline has not been enough to stop biodiversity loss, and new perspectives are necessary. It adds another framing to re-contextualise nature with the social, considering the abundant relationships, benefits, shared labours, and moments of care between humans and non-humans. This conceptual intervention engages with big data and new technologies to open up our sense of where and how we interact with living beings that exist all around us. Practically speaking, this may mean existing forms of conservation take on new meaning. For example, while

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habitat protection can help to conserve many functional collectives, ectomycorrhizal fungi are threatened by air pollution, strengthening the need to consider clean air as part of biodiversity conservation.

Biodiversity is defined as differences among life at all scales, from genetic to ecosystem level, but in practical terms and often at the science-policy interface, species protection and management remain central. Ultimately, counting and tracking species to document biodiversity is problematic because it maintains a focus on visible, countable, identifiable species. The focus on micromycetes has highlighted a form of life at a scale previously unconsidered in conservation, drawing attention to socio-natural conservation in a new way. Through this interdisciplinary research, I focused on the scientific process that allows us to know micromycetes, and the context and conceptual richness that knowing enables. Living with the abundance and the uncertainty of micromycetes and other microbes creates a conservation in which we must embrace uncertainty, but not one in which we must live in fear of defeat.

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## Data availability

Due to privacy restrictions under this approval, the ethnographic data included in this project is not accessible. Scientific publications included in the reflexive literature analysis are available per publishing guidelines.

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