

The delicate umbrellas of this *Mycena* species last only fleetingly, while its fungal mycelium persists, mostly obscured within the log it is rotting. Photo: Alison Pouliot

# A Forgotten Kingdom

Ecologically industrious and alluringly diverse, Australia's puffballs, earthstars, jellies, agarics and their mycelial kin merit your attention. Ecologist **Alison Pouliot** ponders our bonds with the mighty fungus kingdom.

As the sun rises, I venture off-track into a dripping forest in the Otway Ranges. Mountain ash tower overhead, their lower trunks carpeted in mosses, lichens and liverworts. The leeches are also up early and greet me with enthusiasm.

A white scallop-shaped form at the base of a manna gum catches my eye. *Omphalotus nidiformis*, the ghost fungus. A valuable marker. If it's dark when I return, the eerie pale green glow of this luminous fungal cairn will be a welcome beacon.

Descending deeper into the forest, a damp funk hits my nostrils, signalling fungi. As my eyes adjust and the morning lightens, I make out diverse fungal forms in cryptic microcosms. Elegant pink parasols adorn a fallen log. Carmine fungal brackets wear lichen skirts. Transparent goblets capture morning drizzle. With so many fungi to meet, identify, contemplate and photograph, there's no time to waste.

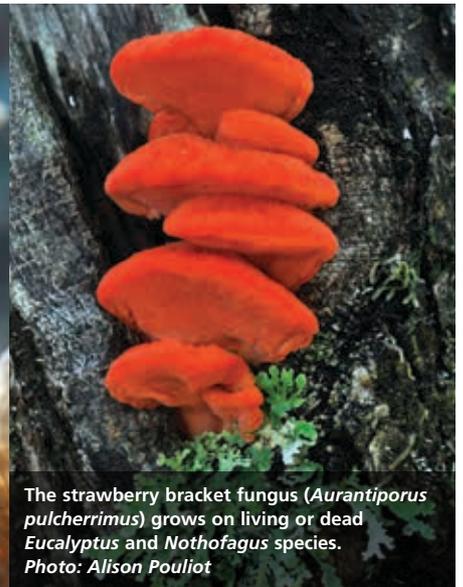
Fungi have been dubbed the 'forgotten kingdom' – their ubiquity and diversity contrast with the sparseness of knowledge about them, they are neglected in conservation despite their ecological significance, and their aesthetic and natural history fascination are largely unsung in popular culture. The term 'flora and fauna' is usually unthinkingly assumed to cover the spectrum of visible life. I am part of a growing movement of fungal enthusiasts dedicated to lifting the profile of the 'third f' in science, conservation and society. It is an engrossing quest, not only because of the alluring organisms themselves but also for the curiosities of their social and cultural associations – featuring fears and fables, superstitions and suspicions, reverence and revulsion. There is much to explore, not just in the wild, but in the many ways for us to perceive, know and appreciate fungi.



The ghost fungus (*Omphalotus nidiformis*), a saprobe, forms clusters of fruitbodies on living and dead trees. It can glow in the dark (bioluminescence), which may attract nocturnal animals that help to disperse its spores. Photo: Alison Pouliot



The leathery goblet (*Cymatoderma elegans*) forms funnel-shaped fruitbodies on rotting logs in wet forests. Photo: Alison Pouliot



The strawberry bracket fungus (*Aurantiporus pulcherrimus*) grows on living or dead *Eucalyptus* and *Nothofagus* species. Photo: Alison Pouliot

### Fungi are ... fungi

Without the insights or instruments of modern science, the Swede known as the father of taxonomy, Carl Linnaeus, could be forgiven for his two-kingdom categorising of life as either animals or plants. But three centuries later, confusion about the identity of fungi is still so prevalent that erudite British mycologist Paul Cannon found it necessary to characterise them like this: 'Let me start by saying what a fungus isn't... It isn't a plant, and it isn't an animal. It's a ... fungus.' A good start. But forging a popular identity for fungi needs more than a definition by exclusion.

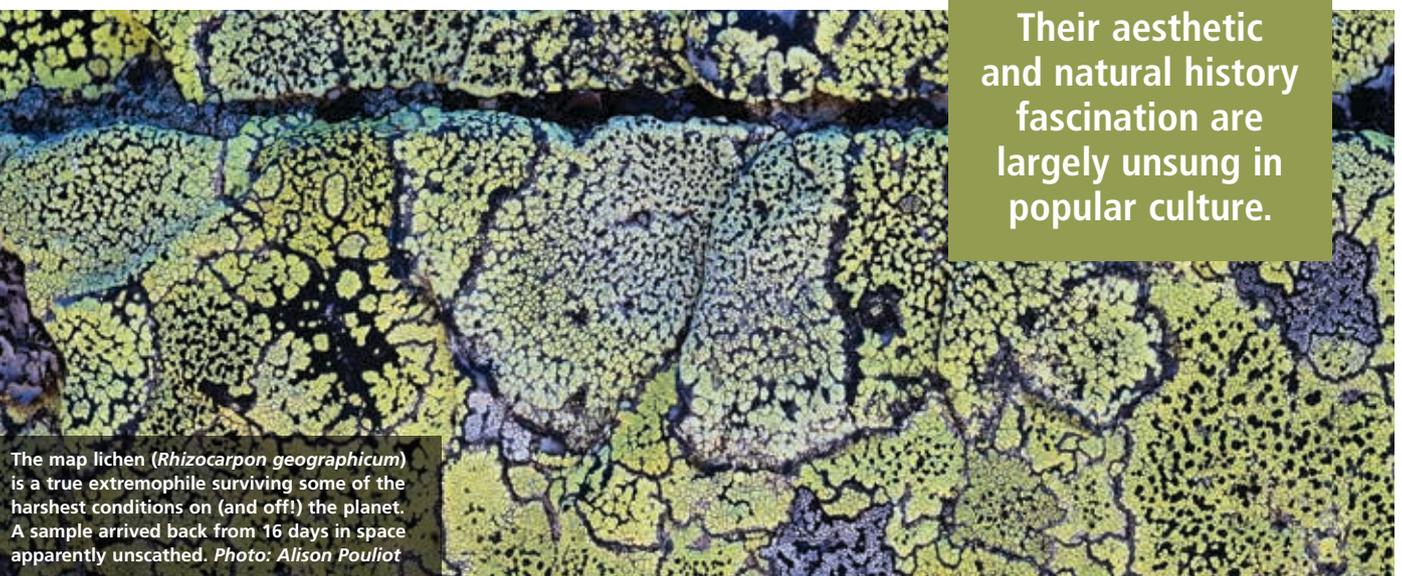
The historical lumping of fungi with plants seems reasonable as fungi, like plants, are immobile and were presumed to photosynthesise. But we now know that fungi obtain their food externally by secreting enzymes to break down complex organic compounds that they absorb as simple sugars. Also unlike plants, the cell walls of fungi contain chitin, a tough polymer that features

also in the exoskeletons of arthropods such as crustaceans and insects. These and other traits not only distinguish fungi from plants, but reveal their closer relatedness to animals. Fungi share a more recent common ancestor (thought to be a flagellated protist) with us than with plants.

For over half a century fungi have been assigned their own kingdom. Some fungi (such as the chytrid fungi that infect amphibians) and fungus-like organisms (such as slime moulds) occupy two further kingdoms – the Chromista and Protoctista.

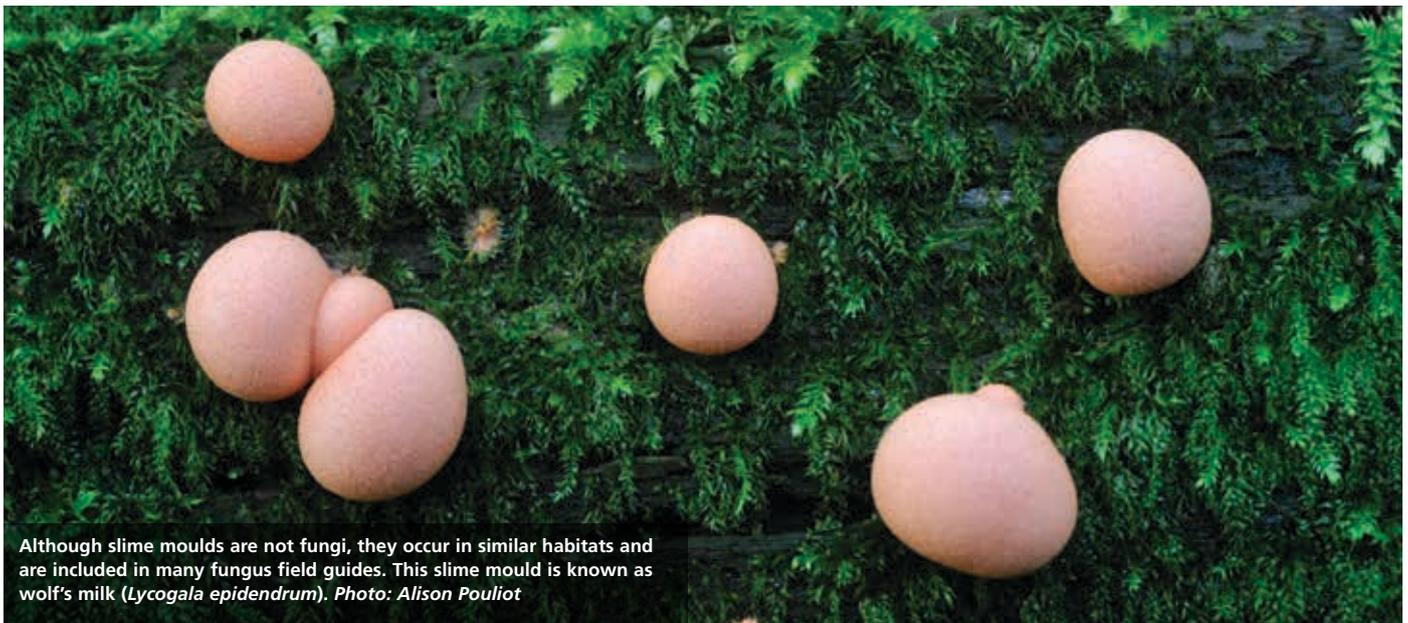
While for many people the word fungus implies a cap-and-stalk style mushroom, this structure represents just the proverbial tip of the fungal iceberg, its fruitbody (or sporocarp). The actual fungus consists of a network of elongated cells called hyphae (collectively known as mycelium) within soil, wood or other substrates. They range in size from millimetres to hundreds of hectares, the largest organisms on Earth.

Because their mycelial tapestry is hidden from view, fungi are usually only conspicuous when, every now and again, in response to changes in temperature, water and other factors, their fruitbodies emerge. Most appear sporadically and fleetingly, some for just hours, while others such as bracket fungi are persistent and perennial, and others such as truffles do not emerge at all. From these fruitbodies, spores (the fungal equivalent of seeds) are discharged and dispersed by all manner of ingenious mechanisms. Gilled fungi use an elaborate ballistic mechanism (ballistospory) to explosively catapult spores into the air, triggered by changes in turgor pressure. Puffballs rely on the energy of a raindrop or the nudge of a clumsy animal to compress their peridia (the 'balls' packed with spores) and 'puff' the spores out through a pore on top. Flies spread spores for stinkhorns, drawn to the irresistible stink of a slimy spore-mass atop their phallus-shaped fruitbodies. ▶



The map lichen (*Rhizocarpon geographicum*) is a true extremophile surviving some of the harshest conditions on (and off!) the planet. A sample arrived back from 16 days in space apparently unscathed. Photo: Alison Pouliot

Their aesthetic and natural history fascination are largely unsung in popular culture.



Although slime moulds are not fungi, they occur in similar habitats and are included in many fungus field guides. This slime mould is known as wolf's milk (*Lycogala epidendrum*). Photo: Alison Pouliot

## Numbering and naming

Because mycologists (scientists who study fungi) are rare, only about 15,000 Australian fungi have so far been scientifically described. This includes terrestrial species in habitats from deserts to alpine peaks, as well as marine and freshwater species. Around 7000 are macrofungi, which form fruitbodies such as mushrooms or puffballs that can be discerned by the human eye. The other 8000 or so are microfungi observable only with one's nose wedged in a microscope.

The majority of the fungus species inhabiting the Australian continent and seas are yet to be named. Estimates vary but the total could be as many as a quarter of a million species (based on a surmise that there are ten times as many fungus as plant species). One hectare of eucalypt forest may harbour 1000 fungus species, possibly more. Due to our dire lack of taxonomists, a full accounting of Australia's fungal riches will be a long time coming.

How many fungi can you name? And how does this compare with flora and fauna? If you can name even a dozen fungus species, you are probably a mycologist, mycophagist (fungus-eater) or keen naturalist. Names matter – for anonymous species are inevitably neglected. One positive advance in the past couple of decades has been a proliferation of field guides to make identification more widely possible (see the list page 19).

## Fungal services

Although most fungi lack names, their pivotal roles, at least in terrestrial ecosystems, are well recognised scientifically – more than enough to justify the contention by David Minter (president of the International Society for Fungal Conservation) that, 'None of the species

we work with in nature conservation, humans included, could survive in a world without fungi.' Particularly as recyclers and symbionts, but also as parasites, food and habitats, fungi perform vital and often exclusive services that underpin the persistence and resilience of ecosystems.

The fungi known as saprobes or decomposers secrete potent enzymes to break down recalcitrant compounds such as lignin and cellulose. Without them, nutrients would remain locked up in great mounds of organic debris, for fungi are the major recyclers of carbon and nutrients from dead plants.

Other species form mutually beneficial relationships with plants. In mycorrhizas the fungal mycelia either form a sheath around the tiny rootlets of plants or directly enter rootlet cells to greatly extend the plant's capacity to penetrate more soil and gain access to water and nutrients, particularly important in Australia's infertile soils. The plant returns the favour by providing the fungus with sugars from photosynthesis.

Another symbiotic relationship with plants involves endophytes, which are microfungi (or bacteria) that live inside most plants and are thought to benefit their hosts by enhancing plant growth, drought and salt tolerance, as well as resistance to insects and diseases. Endophytes benefit from a protective environment and supply of nutrients.

Yet another symbiosis is that of lichens, in which an algal and fungal partner unite, sometimes in a ménage à trois

with a cyanobacterium. Combining their respective talents has enabled lichens to colonise some of the most inhospitable habitats on earth, from salt-ravaged intertidal zones to arctic peaks, earning them the title of extremophiles. Even a trip to outer space with extreme cosmic and solar radiation did not kill the map lichen (*Rhizocarpon geographicum*), which was able to respire, photosynthesise and reproduce on return to Earth.

A third common way of life for fungi is parasitism, on hosts that include plants, animals and other fungi. From the ova of barnacles to the armpits of *Homo sapiens*, few animals are likely to be free of fungal parasites. Although parasites get a bad rap, they are a natural part of healthy ecosystems and perform

essential functions by influencing species interactions, regulating populations (natural biological control) and interacting with other ecological drivers to affect energy budgets and nutrient cycling. Recent work in the

Amazonian basin has identified a major role for parasitic fungi in regulating tropical tree diversity and structuring tropical forests. In what is known as negative density dependence, these host-specific fungi, along with plant-eating insects, prevent single plant species from dominating forests because they inflict more damage where their hosts are more abundant.

Fungi are also a source of food for many animals, and potoroos and bettongs often eat little else (see Truffles & Mammals in *Wildlife Australia* Winter 2013). In other examples of cross-kingdom symbioses, some species of termites, ants and beetles

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cultivate fungal gardens. Ambrosia beetles inoculate galleries they excavate in wood with fungal spores from their natal nests (see The World's Most Social Beetle in *Wildlife Australia* Summer 2013) and African termites from family Macrotermitinae plant fungal spores in combs of chewed-up woody material inside their mounds. These animals effectively 'outsource' to fungi the digestion of cellulose.

Depending on one's perspective, the fungi could be regarded as the active cultivators in these arrangements, having enticed their hosts to provide them with a haven safe from fungal competitors and with ideal growing conditions.

The complex and convoluted architecture of fungal fruitbodies provide important invertebrate real estate. Fungi frequently provide shelter as well as food for adults or juveniles of millipedes, nematodes, slugs, flies, mites, beetles and springtails. Regular photographers of fungi have probably been glared at by the territorial male fungus fly (*Tapeigaster* species) as it staunchly defends its fungal patch and ovipositing female.

### Conserving fungi

In contrast to their ecological prominence, fungi are inconspicuous in Australia's environmental strategies, policies and laws. The national biodiversity conservation strategy fails to even mention them. And just two species are listed under our national environmental law (the Environment Protection and Biodiversity Conservation Act) but not for their protection: the exotic frog pathogen chytrid fungus and the plant pathogen *Phytophthora cinnamomi* (or 'root

rot', actually a fungus-like organism rather than a fungus) are listed as key threatening processes. This is emblematic of the place of fungi in conservation, with the threats of fungal pathogens overshadowing concerns to protect ecologically beneficial fungi.

Under state laws, just 14 species of non-lichenised fungi and one fungal community are listed as threatened.

Because conservation priorities are largely shaped by what is listed as threatened, the near absence of fungi on such lists is one major reason for their neglect.

Assessment criteria for listing species rarely allow for the many ways in which fungi differ from animals and plants. Baseline data on fungal distributions, abundance and relationships that allow us to track changes over time and assess their vulnerability are mostly lacking. Even for fungi that send up fruitbodies that can be monitored, determining their abundance can be difficult as one fungus can produce multiple fruitbodies.

Australian mycologist and initiator of Fungimap (see page 19) Tom May has proposed a more comprehensive approach to monitoring that is inclusive of fungi. It is more than justified, he argues, by their megadiversity, their important functional roles (many of which are not duplicated in other kingdoms) and the high rate

of mutualisms with other kingdoms. Through Fungimap and fungus keys and field guides, sufficient knowledge now exists for inclusion of at least some fungi

in biodiversity monitoring.

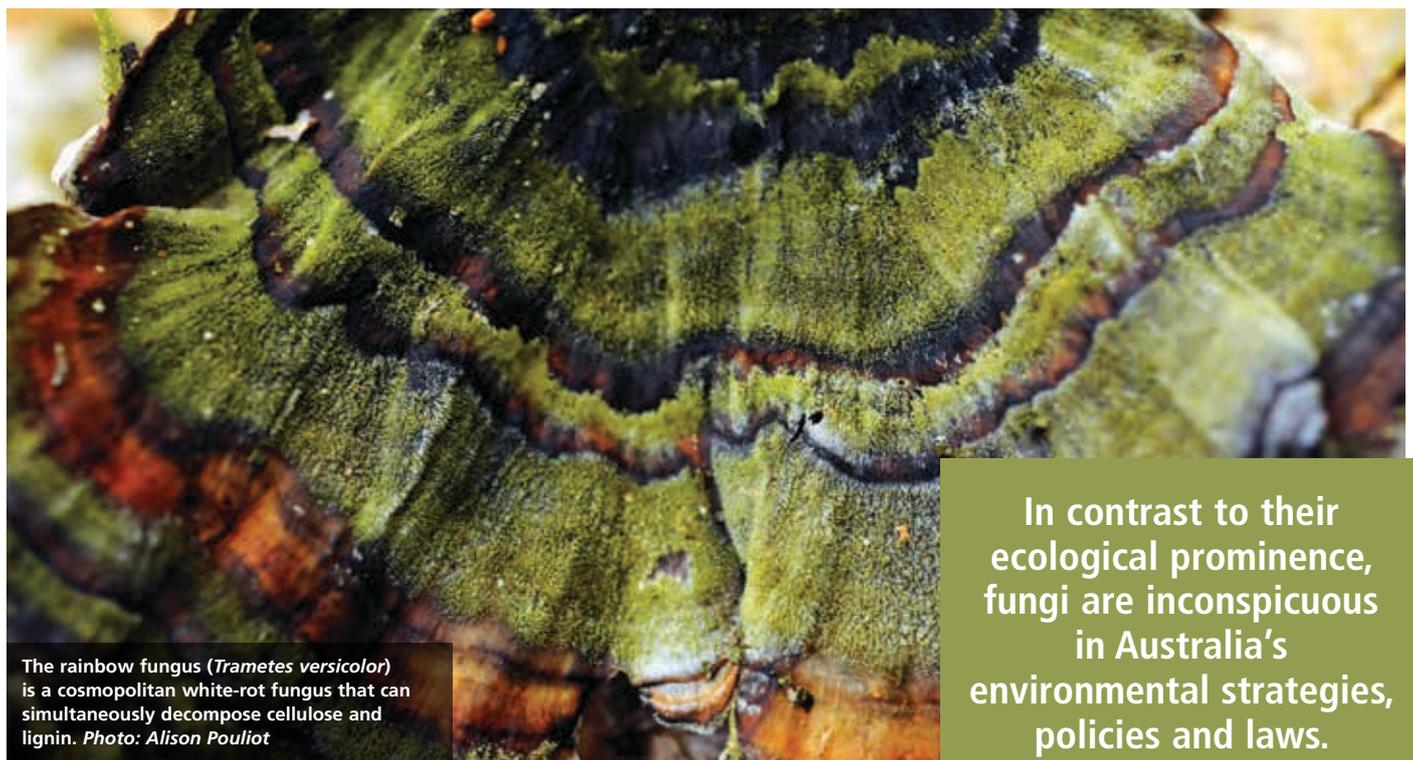
Another reason for the neglect of fungi is that Australia's mycologists are, in contrast to the plethora of fungal species, drastically few in number. Focused on macrofungi are just two

permanently employed taxonomists and two fungal ecologists, and a handful of others on short-term contracts or retired, honorary or non-salaried. Probably a dozen or so mycologists work on microfungi but they mostly focus on crop pathogens.

It is often assumed that fungi are protected under the umbrella of conservation programs for better known species (plants and animals) or for their habitats, but the effectiveness of this surrogacy approach is largely untested. The diversity of fungi and the specificity and complexity of their ecological interactions make it unlikely that surrogacy approaches will be comprehensively effective.

Take wood-decaying fungi, for example, which are highly diverse in Australia's forests and woodlands and provide essential ecosystem functions through decomposition and nutrient cycling. ▶

Many fungi are very choosy about their habitat, inhabiting the wood only of specific tree species and tree parts at a particular stage of decomposition.



The rainbow fungus (*Trametes versicolor*) is a cosmopolitan white-rot fungus that can simultaneously decompose cellulose and lignin. Photo: Alison Pouliot

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Many are very choosy about their habitat, inhabiting the wood only of specific tree species and tree parts at a particular stage of decomposition. During its lifetime a large tree may host hundreds of different fungus species. The habitat specificity of many fungi means that species (and their functions) can be lost even if all plant species in the same ecosystem are conserved.

Because the habitats of wood-decay fungi are transient and local extinction is inevitable as their substrate is lost to decay, their survival depends on being able to colonise new sites. This and their low population densities make them especially vulnerable to habitat fragmentation and the loss of age variation in forests. Their habitats have been much diminished due to clearing and fragmentation of woodlands and forests and, more recently, through firewood collection and forestry burning or chipping of fallen wood considered to be a fire hazard or economically valueless. Cattle grazing in woodlands also diminishes habitat by altering the composition and structure of plant communities.

Native grasslands are often rich in specific fungal families (such as

Hygrophoraceae, Entolomaceae and Clavariaceae), which are also unlikely to be adequately conserved under surrogacy approaches. Grasslands have traditionally been a low conservation priority and those in agriculturally productive areas have been largely decimated. There is too little known about fungi in other habitats such as wetlands, dunes and alpine areas to determine how well they would fare under the umbrella of conservation focused on other species.

The inconspicuousness of fungi, making them seem irrelevant, and their complex life histories, making them difficult to comprehend, are not the only barriers to their conservation. It may also have much to do with popular misperceptions and cultural biases.

### Fungi in culture

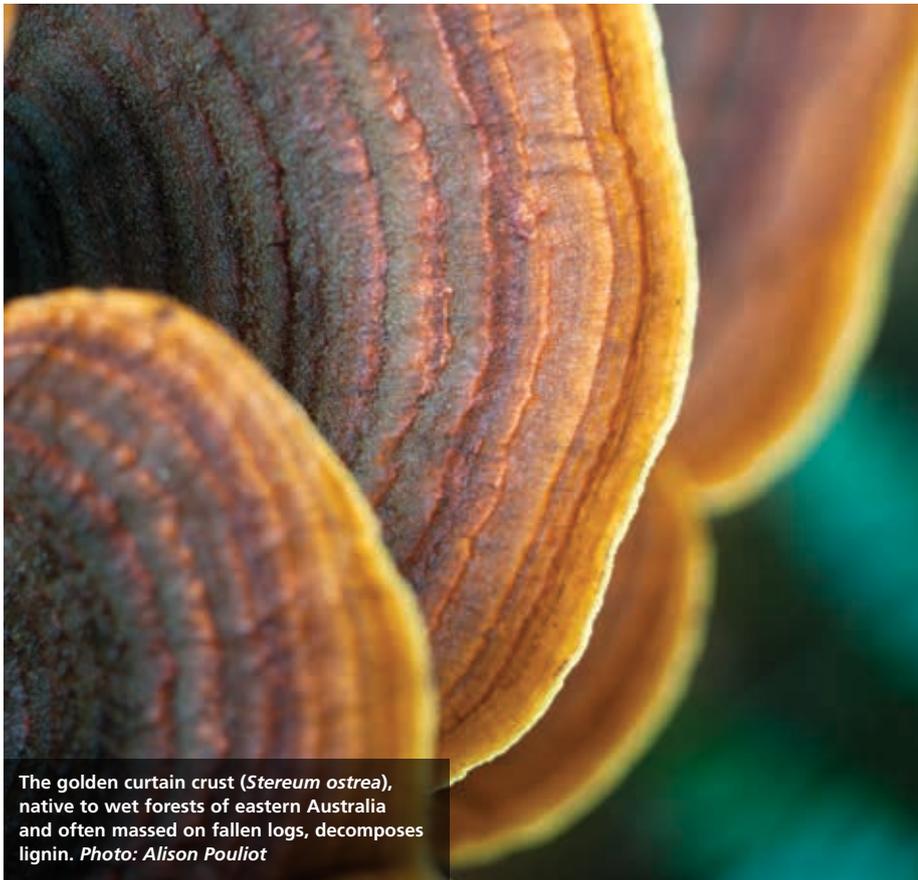
Without positive human connections to fungi, it is extremely difficult to inspire a conservation ethic. As British mycologist David Moore notes (for microbial species), their demise 'is not an emotional issue for humans'. Although there are special challenges in inspiring care for organisms that live most of their lives out of human sight, the neglect of fungi may be exacerbated by deeply embedded fears

and a typecasting of them as dangerous or horrible.

Many people may even welcome the idea of a world with fewer fungi. One has only to look at synonyms for fungi in any thesaurus – *blight, slime, disease, affliction, scourge* – to recognise that perceptions of fungi are laden with negative connotations, at least in English-speaking cultures. Some cultures are more predisposed to mycophobia (fear of fungi) than others, and Australians of British heritage seem especially prone. Many fears are deeply entrenched in cultural histories, and once species are framed negatively, it can take a lot of undoing to present them in a positive light.

Throughout the centuries and across the globe, fungi have acquired many different cultural meanings, including in witchcraft, mythologies and religious rituals. Fairy rings (known as hexen rings in German and ronds de sorcières in French) were associated with the high revelry of witches, dancing elves, winged dragons, bulging-eyed toads, an assortment of devils, demons and deities, and as Sir Arthur Conan Doyle remarked, 'the gambols of the little people'. Puffballs, with fruitbodies that often succumb to a well-aimed kick, are thought to have been everything from fallen stars to warts shed from witches' noses. Take heed that kicking a mushroom was alleged (in eastern Europe) to bring seven years of bad luck!

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The golden curtain crust (*Stereum ostrea*), native to wet forests of eastern Australia and often massed on fallen logs, decomposes lignin. Photo: Alison Pouliot



The beech orange (*Cyttaria gunni*), which grows on *Nothofagus* species, was eaten raw by Australian Aborigines. Photo: Alison Pouliot

In many cultures, one ancient and highly meaningful interaction with fungi is foraging – for subsistence, culinary delicacies or medicine. Hallucinogenic species have also long been sought by many people for their mind-altering potential.

The edibility and toxicity of Australian fungi are little known. Fungi used by Australian Aborigines (as documented by Arpad Kalotas) include native bread (*Laccosphaerium mylittae*), the beech orange (*Cyttaria gunni*) and various truffle species. Because traditional knowledge of fungi has been mostly lost, fungus foraging is little practiced nowadays in Australia, despite many edible European species having been introduced here. Foraging is far more common in Europe.

Foraging obviously brings tangible rewards but has cultural and social significance beyond what can be popped into the mouth. This is implied in part by the relatively poor nutritional value of mushrooms. The cultural importance of fungi is also evident, notes Anglo-American mycologist Nicholas Money, in the fact that ‘people in the most heavily [radiation]-contaminated districts of Ukraine and Belarus continue to collect and consume wild mushrooms’. In *Morel Tales*, an insightful ethnographic account of fungus foraging in the United States where as many as 30 million people go mushrooming, sociologist Gary Fine explores the ways in which people draw meaning from collecting, identifying and consuming fungi. Although superficially

it seems that foraging has mainly utilitarian value, often it ‘is seen not so much as an extractive activity as one that demands being in close touch with the environment’. Fine analyses the ‘emotional, cognitive and cultural meanings’ that foragers and foragers give to fungi, ‘exploring how one corner of the world is filled with a richness of which most people are unaware’.

### Fungal futures

Understanding how to foster positive ‘emotional, cognitive and cultural meanings’ is essential for achieving a more prominent place for fungi in science, conservation and culture. We can learn from research into attitudes towards other marginalised organisms such as invertebrates that have gradually gained more recognition. The classification of the different ways in which humans value invertebrates, developed by social ecologist Stephen Kellert, is a useful framework for investigating where we can focus our promotional efforts on behalf of fungi: ecological (respect for the role of fungi in ecological processes), aesthetic (appreciation of fungal beauty and bizarreness), naturalistic (interactions with wild fungi), utilitarian (human uses for fungi), humanistic (cultural and emotional ties to fungi), moralistic (concerns for fungus conservation) and negative values (fear or dislike of fungi).

As with much else in nature, direct sensory engagement with fungi in the wild is a powerful way to transform perceptions and erode fears. The aesthetics of fungi revealed on close inspection can inspire wonder.

Words and concepts are also powerful, particularly when so much about fungi is imperceptible to the senses. While it’s usually scientists who write about fungi, nature writers could play a more influential and imaginative role in cultivating positive sentiments toward fungi. There are narrative riches in exploring the interactions of fungi with other species including humans. One challenge is, as literary theorist Ursula Heise puts it, to analyse the ‘narrative templates and metaphors’ used to think about nature,

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### FUNGIMAP

Fungimap is a national citizen-science organisation dedicated to raising the profile of Australian macrofungal diversity. Fungimap maintains the National Australian Fungimap Database, which has over 100,000 fungal distribution records received from over 700 contributors. In addition to delivering training in fungal identification and surveying, Fungimap is active in fungal conservation initiatives. Further information: [fungimap.org.au](http://fungimap.org.au)

to open up new ways to convey the significance and meaning of fungi.

To include fungi more profoundly within human lives, we need the perspectives of many different disciplines. Positively, it seems that fungi may be infiltrating new audiences and capturing the attention of artists, ethnographers, aesthetes, conservationists, philosophers, poets and others. Stories and representations of fungi are appearing in academic and popular literature, exhibitions and other forums where they’ve not been previously, offering opportunities for new and richer interpretations of the significance of fungi. Like the first rays of light infiltrating the forest canopy, it seems we may be on the verge of a fungal awakening. ■

**SOME INTERESTING BOOKS ON FUNGI:** Fine G. 1998. *Morel Tales: The Culture of Mushrooming*. Harvard University Press ■ Hudler G. 1998. *Magical Mushrooms and Mischievous Moulds*. Princeton University Press ■ Kendrick B. 1992. *The Fifth Kingdom*. Mycologue Publications ■ Marley G. 2010. *Chantarelle Dreams, Amanita Nightmares*. Chelsea Green Publishing Company ■ Money N. 2011. *Mushroom*. Oxford University Press ■ Moore D. 2013. *Fungal Biology in the Origin and Emergence of Life*. Cambridge University Press ■ Moore D, Nauta M, Evans S, Rotheroe M. 2001. *Fungal Conservation, Issues and Solutions*. Cambridge University Press.

**SOME FUNGUS FIELD GUIDES:** Grey P, Grey E. 2005. *Fungi Down Under*. Fungimap ■ McCann I. 2003. *Australian Fungi Illustrated*. Macdown Productions ■ Young A. 2005. *A Field Guide to the Fungi of Australia*. UNSW Press ■ Fuhrer B. 2005. *A Field Guide to Australian Fungi*. Blooming Books ■ Gates G, Ratkowsky D. 2014. *A Field Guide to Tasmanian Fungi*. Tasmanian Field Naturalists Club ■ McMullan-Fisher S, Leonard P, Guard F. 2014. *Australian Subtropical Fungi*. Suncoast Fungi.

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