21st Century Guidebook to Fungi, Second Edition of the online version, by David Moore, Geoffrey D. Robson and Anthony P. J. Trinci

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Chapter 13: Ecosystem mycology: saprotrophs, and mutualisms between plants and fungi

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In this Chapter on ecosystem mycology we cover fungi as saprotrophs, and the mutualisms between plants and fungi, concentrating on fungi as recyclers that can make the earth move. Fungi also cause food contamination and deterioration through their formation of toxins, although some of these, like statins and strobilurins, are exploited commercially for our own practical purposes.

The ability of fungi to degrade wood makes them responsible for the decay of structural timber in dwellings, but on the other hand enables them to be used to remediate toxic and recalcitrant wastes. A downside, though, is that wood decay fungi release chlorohydrocarbons, potent greenhouse gases, to the atmosphere and thereby potentially contribute to global warming.

Interactions with plants dominate the rest of the Chapter. We describe all types of mycorrhiza: arbuscular (AM) endomycorrhizas, ericoid endomycorrhizas, arbutoid endomycorrhizas, monotropoid endomycorrhizas, orchidaceous endomycorrhizas, ectomycorrhizas and ectendomycorrhizas. The effects of mycorrhizas and their commercial applications, and the impact of environmental and climate changes are also discussed. Finally, we introduce lichens, endophytes and epiphytes.

Evidently, fungi contribute to a broad and vibrant network of interactions with all members of the plant, animal, and bacterial kingdoms (Prosser, 2002). Because of their unique attributes, fungi in particular play vital roles in most ecosystems.

They act as **mutualists** (forming symbiotic associations in which all partners benefit) of virtually all plant species, and a great many animals; but arguably the most important of these are the lichens, which are usually associations between a fungus and a green alga, and the mycorrhizal association between plants and fungi. Most plants depend on mycorrhizal fungi for their survival and growth, the fungus taking photosynthetic sugars from the host in return. The benefits of mycorrhizas to plants include efficient nutrient uptake, especially phosphorus, because the fungus extends the nutrient-absorbing surface area of the roots, but water uptake through the mycorrhiza enhances plant resistance to drought stress, and the mycorrhiza provides direct or indirect protection against some pathogens (see below).

Parasitic and **pathogenic** fungi infect the living tissues of plants, animals, and other fungi, causing injury and disease that adds to the selection pressure on their hosts (see Chapters 14, 15 and 16). Even fungal plant pathogens have a positive effect on the natural environment by enriching its species structure. Plants killed by disease provide organic matter for nutrient cycling organisms; dead branches or heart rot in live trees create habitats for cavity nesting animals, while gaps in stands of dominant plants caused by disease allow development of other plants, contributing both to species diversity and diversity of food for animals, from insects to elk.

13.1 Ecosystem mycology

Fungi are the **saprotrophs** that perform the decomposition processes that contribute to organic and inorganic nutrient cycling. Clearly, fungal decomposition of dead organic matter, be it wood or other plant litter, animal dung, or cadavers and bones, is an essential ecosystem function because it maintains soil nutrient availability (see below). But there is another significant contribution along the way: fungi that decay wood soften the timber sufficiently to allow small animals (birds, reptiles, amphibians, insects and mammals) to make burrows and nests.

Fungal products ***aggregate soil particles*** and organic matter, improving drainage and aeration; and by so doing they create habitat diversity for many other organisms (see our discussion of glomalin in Section 6.8).

Fungi serve as both prey and predators of many soil organisms, including bacteria, other fungi, nematodes, microarthropods, and insects (Wall *et al*., 2010; Crowther *et al*., 2012; Menta, 2012; Ngosong *et al*., 2014) (see Sections 1.5, 11.2, and Chapter 15).

Mushrooms and truffles are consumed by many animals including large mammals like primates, deer, and bears, and many small mammals rely on mushrooms and truffles for nearly their entire food supply. The fungal mycelium is an equally important nutritional resource for many microarthropods (see Section 11.2).

The significance of fungi in nature means that changes in the composition and functioning of fungi in a community can have sweeping effects on the diversity, health and productivity of our natural environment. Fungal **diversity** is also called **richness** (Andrew *et al*., 2019) and molecular methods ('**metagenomics**') are now allowing this to be studied directly (Lindahl & Kuske, 2013). Although species of fungi, bacteria, nematodes, and arthropods that typically dominate terrestrial ecosystems in terms of species richness, most conservation work is unfortunately concentrated on vertebrates and vascular plants. Yet there is evidence that land management practices can affect fungal diversity.

In most environments, most of the larger, showy and fleshy mushrooms that are readily seen, as well as truffles beneath the surface, are **mycorrhizal**. Obviously, diversity of mycorrhizal species will be influenced, if not determined, by plantings of their potential hosts. However, management practices can also affect the diversity of saprotrophic fungi; indeed, in Northern Europe intensive management of forest is associated with decline in species diversity of wood-degrading saprotrophic fungi. This appears to result from management regimes that remove woody debris from managed forests. Diversity of such species is positively correlated with both the quality and quantity of woody debris left in a forest and coarse woody debris even promotes the abundance and diversity of truffles. It is counterproductive to allow this to occur as change in the diversity and abundance of wood-degrading fungi will adversely affect the recycling of key nutrients and the provision of ecological niches in the managed community.

The result is that the influence extends beyond the plant communities to all those other organisms that interact with fungi, from insects and slugs that depend on fungi for food, to the vertebrates that eat the invertebrates. And, of course, it's not just the commercial forests to which this applies. Amenity land (public garden and park land) is an increasingly important aspect of the urban environment which so many of us inhabit, but here, too, excessive tidiness can adversely affect the biodiversity and diminish the recreational value of the resource (Czederpiltz *et al*., 1999; Floren *et al*., 2015; Juutilainen *et al*., 2014; Heilmann-Clausen *et al*., 2017).

From several aspects of the above it is evident that fungi contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of planet Earth. But these are just a few examples of the ways that fungi make this contribution; descriptions of many other examples occur throughout this book. This is the fungal part of the interface between economics and biology. Overview of the many benefits that the natural world offers to humans views those benefits as a range of ***services*** (first called **Nature's Services**; Daily, 1997) to which monetary value (the ***natural capital***) can be attached. The hope being that understanding the value of the natural systems on which we are all vitally dependent will encourage greater efforts to protect the Earth's basic life-support systems before it is too late (on the principle '***money talks***'). The description '**ecosystem services**' was adopted by Costanza *et al*. (1997), and this name is now the most widely used.

Costanza *et al*. (1997) estimated the (minimum) economic value of the entire biosphere to be an average of US$33-trillion (that is, US$33 × 10^{12}) per year. This is equivalent to US$50-trillion at 2018 prices. To put this into perspective, the Gross Domestic Product of the United States of America ran at a rate of $20-trillion a year during the second quarter of 2018. Ecosystem services is now the principal concept in ecology. By March 2017, the paper in the journal *Nature* by **Robert Costanza** *et al*. (1997) had been cited over 17,000 times and **Gretchen Daily**'s book (Daily, 1997) had been cited over 6,000 times, making them among the most highly cited works in ecology to date (Costanza *et al*., 2017). In **a PDF attached as an appendix to this document** we provide a few more reference sources for ***Ecosystem Services*** and a Table listing the fungal examples you can find in the 21st Century Guidebook to Fungi.

World agriculture's vulnerability to climate change is increasingly being expressed as its **resilience**. Agricultural resilience, defined as the capacity of the system to absorb shocks and stresses (to agricultural production and farming livelihoods), has become a distinct policy objective for sustainable and equitable development (Bousquet *et al*., 2016). The resilience concept and its relationships to biodiversity, ecosystem services, and socioeconomics are explored fully by Gardner *et al*. (2019).