21st Century Guidebook to Fungi
Ecosystem Services

Ecosystem services are the benefits people obtain from ecosystems; ultimately, these services support human life so, ecosystem services are the life support systems of the planet. The concept of ecosystem services is 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 $\times 10^{12}$) 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).

Historically, the nature and value of planet Earth's life support systems have largely been ignored until their disruption or loss revealed their importance. The pro-active evaluation of ecosystems and biodiversity has become an important field of investigation for economists and ecologists alike, largely motivated by the search for arguments in favour of broader conservation policies.

At the request of the then United Nations Secretary-General **Kofi Annan** in the year 2000, the first major scientific appraisal of the world's ecosystems and the services they provide, known as the ***Millennium Ecosystem Assessment***, was done between 2001 and 2005 and involved the work of more than 1,360 experts worldwide [see https://www.millenniumassessment.org/en/About.html].
The first overview of the project, describing its conceptual framework, was published in 2005 in the 155-page book Ecosystems and Human Well-Being: Synthesis (published by Island Press, Washington; ISBN: 9781597260404).

Wikipedia [https://en.wikipedia.org/wiki/Ecosystem_services] provides a quick introduction, and check out the following **websites** for further details:

http://www.greenfacts.org/en/ecosystems/index.htm
https://www.millenniumassessment.org/en/Index-2.html
https://www.iucn.org/about
https://www.iucn.org/theme/ecosystem-management

and the following **publications**:

Cavanagh, R.D., Broszeit, S., Pilling, G.M., Grant, S.M., Murphy, E.J. & Austen, M.C. (2016). Valuing biodiversity and ecosystem services: a useful way to manage and conserve marine resources? Proceedings of the Royal Society B: Biological Sciences, 283: article 20161635. DOI: https://doi.org/10.1098/rspb.2016.1635.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. Nature, 387: 253. DOI: https://doi.org/10.1038/387253a0.

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S. & Grasso, M. (2017). Twenty years of ecosystem services: How far have we come and how far do we still need to go? Ecosystem Services, 28: 1-16. DOI: https://doi.org/10.1016/j.ecoser.2017.09.008.

Daily, G.C. (ed) (1997). Nature's Services: Societal Dependence on Natural Ecosystems. Washington, DC: Island Press. 412 pp. ISBN-10: 1559634766, ISBN-13: 978-1559634762.

Dighton, J. (2016) Fungi in Ecosystem Processes, 2nd Edn. 382 pp. Boca Raton, Florida: CRC Press. ISBN 9781482249057.

Dighton, J. & White J.F. (eds). (2017). The Fungal Community: Its Organization and Role in the Ecosystem, 4th Edition. 597 pp. Boca Raton, Florida: CRC Press. ISBN 9781498706650.

Farber, S., Costanza, R., Childers, D.L., Erickson, J., Gross, K., Grove, M., Hopkinson, C.S., Kahn, J., Pincetl, S., Troy, A., Warren, P. & Wilson, M. (2006). Linking ecology and economics for ecosystem management. BioScience, 56: 121-133. DOI: https://doi.org/10.1641/0006-3568(2006)056[0121:LEAEFE]2.0.CO;2.

Gadd, G.M. (ed.). (2006). Fungi in Biogeochemical Cycles (British Mycological Society Symposium volume). Cambridge, UK: Cambridge University Press. ISBN-10: 0521845793, ISBN-13: 978-0521845793. DOI: https://doi.org/10.1017/CBO9780511550522.

Salles, J.-M. (2011). Valuing biodiversity and ecosystem services: Why put economic values on Nature? Comptes Rendus Biologies, 334: 469-482. DOI: https://doi.org/10.1016/j.crvi.2011.03.008.

Vo, Q.T., Kuenzer, C., Vo, Q.M., Moder, F. & Oppelt, N. (2012). Review of valuation methods for mangrove ecosystem services. Ecological Indicators, 23: 431-446. DOI: https://doi.org/10.1016/j.ecolind.2012.04.022.

Zhang, W., Ricketts, T.H., Kremen, C., Carney, K. & Swinton, S.M. (2007). Ecosystem services and dis-services to agriculture. Ecological Economics, 64: 253-260. DOI: https://doi.org/10.1016/j.ecolecon.2007.02.024.

There are tens of thousands of other publications relevant to this topic. We'll leave you to find the ones that interest you most!

In the following Table we list the examples of ***fungal contributions*** **to Ecosystem Services** you can find in this **online-book**.

Table 13.1. Fungal contributions to ***Ecosystem Services*** you can find in this book

An ecosystem is defined as a dynamic complex of plant, animal, and microorganism communities, together with the non-living environment, interacting as a functional unit. Humans are an integral part of ecosystems. Ecosystem services are the benefits people obtain from ecosystems. Ecosystem services are usually grouped into four broad categories, to which we have added ***ecosystem goods***, defined (in the left-hand column, below) as follows

Ecosystem Service category	**Fungal contributions**	**See Section**
Provisioning such as the production of food, water and other materials	**Food**: this includes the vast range of food products derived from plants, animals, and microbes. So, the fungal contribution ranges from **mushrooms** of several different sorts, **morels** and **truffles**, cultivated and collected, through **yeast** extracts, **mycoprotein** (a **filamentous fungus** isolated from field soil), and all those **fermented** foods (bread, cheese, salami, soy sauce and other soya products, tempeh and miso) but also including meats and dairy products because our farm animals can't digest grass without their **anaerobic fungi**.	3.3 11.2 to 11.6 15.5 17.18 17.20 17.23 17.24 17.25
	And **drink**? Not usually mentioned, but where would we be without beers, wines and spirits? The **yeasts** deriving, even if in prehistory, from natural ecosystems. Citric acid's fizz and the preparation of fruit juices using **fungal enzymes** are other contributions.	17.13 17.14 17.16
	Materials such as wood, jute, hemp and many other products are derived from ecosystems and depend on plants, which all depend on **mycorrhizal fungi** to make their roots work adequately.	13.9 to 13.17
	Similarly, **water supply** depends on erosion control, which needs vegetation for soil retention and the prevention of landslides. Vegetation depends on **mycorrhizal fungi.**	13.9 to 13.17
	Climate regulation. Ecosystems influence climate by either sequestering or emitting greenhouse gases. **Wood decay fungi** have influence here by releasing chlorohydrocarbon volatiles from timber, and by recycling C and N from the soil.	13.2 13.7 13.17
Regulating such as the control of climate and disease; can have impact on local or global climate over time scales relevant to human decision-making (decades or centuries)	**Water supply**. As mentioned above, changes in vegetation, such as conversion of wetlands, the replacement of forests with croplands, or croplands with urban areas, change the water storage potential of the ecosystem. All of which depend on parallel changes in **mycorrhizal fungi**.	13.9 to 13.17
	Waste treatment. Ecosystems can be a source of impurities in water, but **fungal bioremediation** can decompose organic wastes introduced by agriculture and/or industry into inland waters and coastal and marine ecosystems.	13.2 13.6
	Regulation of animal and human diseases. Changes in ecosystems can directly change the abundance of pathogens, leading to **emerging fungal infectious diseases** that seriously endanger clinical practices and threaten animal extinctions in nature.	16.1 to 16.10 16.11 16.12 18.3
	Regulation of plant diseases. Rarely specifically mentioned in these discussions, but fungal diseases dominate in plants, potentially causing sweeping damage to plants of the forest and urban environments (like **Dutch Elm Disease**), as well as crucial crop plants like rice and wheat.	14.3 to 14.8 14.11 14.12 14.17
	Biological control. **Fungal pathogens** can alter the abundance of crop and livestock pests and diseases.	13.19 15.6 16.14 16.15

Supporting services maintain the conditions for life on Earth over extremely long times	Prime examples of supporting services are photosynthetic primary production using CO_2 and water, and photosynthetic production of atmospheric oxygen. At least 90% of the terrestrial plants that do this depend on **mycorrhizal fungi** for their adequate nutrition.	13.8 to 13.16 13.17
	Soil formation is another long term supporting service to which **fungi** contribute their abilities to degrade and manipulate minerals, accumulate metals, and the **lichen** terrestrial pioneer primary producers, which are **mutualistic associations made by fungi** with algae and bacteria. Polymers produced by the most widespread **mycorrhizal fungi** (***glomalin***) control the structure of mature soils	1.2 to 1.8 6.8 13.3 13.18 17.22
	Nutrient cycling is a continued supporting service provided by **fungi** by their ability to **secrete enzymes** into ecosystems that can digest even the most recalcitrant materials (like lignocellulose) to capture the various nutrients those materials contain. **Mycorrhizal** and **saprotrophic fungi** recycle major nutrients for later release by the former to their plant associates, while the many **mycophagous animals** (small and large) benefit by eating the mycelia and fruit bodies of both. Importantly, **fungi** also contribute to water cycling in ecosystems; **mycorrhizas** are major suppliers of water to their hosts and **saprotrophs** translocate water over considerable distances. Section 14.10 shows how the *Rhizobium*-legume symbiosis, which assimilates atmospheric nitrogen into organic compounds, makes use of molecular components derived from the **arbuscular mycorrhizal fungal partner** of the legume to create its symbiotic interface.	1.4 to 1.7 9.7 9.8 10.1 to 10.11 11.1 11.2 13.2 13.10
	Removal of natural wastes (which means dead and dying organisms) from ecosystems is an aspect of the nutrient cycling described in the previous section. However, ***contaminating wastes***, which are mostly the result of human activities can be **recycled by fungi** because they are so adept at producing degradative enzymes. The process is generally called **bioremediation**.	10.1 to 10.11 13.6 17.22 17.26
Cultural such as spiritual and recreational benefits	Contributions of fungi to human cultural activities extend into prehistoric times. Without **anaerobic fungi** to digest the grass they eat there would be no large herbivores to provide skins for clothes, horn for tools or sinews for prehistoric bows and for binding flint arrow heads, handles to blades or spear points to spears. So not much hunting, though there would still be **mushrooms** to gather.	3.3 11.3 15.5 17.20
	The **Neolithic** traveller known as 'Ötzi the Tyrolean Iceman' had three separate **fungal products** among his equipment; one was clearly used as tinder, the others possibly medicinal. Psychotropic fungi have been used since ancient times for mystical purposes by witch doctors and shamans.	11.3 13.4 16.13
	'Flowers used as ornaments' are normally included in this category. One of the largest families of flowering plants, and arguably the most ornamental, are the **orchids**. Orchid seedlings are non-photosynthetic and depend on the **endomycorrhizal fungus partner** for carbon sources; seedling stage orchids can be interpreted as parasitising the fungus.	13.9 13.14
Ecosystem goods This category depends on biodiversity as the source of many such goods	All plant materials that serve as sources of energy (wood, dung, other biomass fuels) depend on **mycorrhizal fungi** enabling the plant to grow in the first place.	13.9 to 13.17
	Increasingly, **yeast fermentation of agricultural wastes** is being used for fuel alcohol production.	17.13 17.22
	Many of today's most widely used **pharmaceuticals** were 'found by accident' as **products of fungi** in natural ecosystems and then developed into industrial chemicals for global use. Traditional medicines (including **nutraceuticals**) also derive from **fungi collected from natural ecosystems** and now cultivated commercially.	18.1 to 18.4 17.15 17.19 18.14
	Many industrial products, **fine biochemicals, biocides, food additives**, and **enzymes** for processing food and other goods, have been developed from metabolites originating from **fungi** isolated from natural ecosystems.	17.14 17.16 18.14
	Production of all natural fibres depends on **fungi** providing nutrition to the organism that makes the fibre; industrial processing, laundering and conditioning of fabrics made from such fibres depends on **fungal enzymes**.	11.3 11.6 17.16
	Foods depending on **fermentation** (with a **variety of fungi**) resulted from traditional use of microbes from natural ecosystems. The foods include mycoprotein, soya foods, tempeh, miso, ang-kak.	17.18 17.25

	Genetic resources are included in this category. This includes all genetic information used in strain breeding and biotechnology. It's also worth remembering that we must thank **research with yeast** for most of what we know about eukaryote cell biology, genetics and molecular biology.	18.5 to 18.13
	The final topic in this category is usually 'Storm Protection'. It's not obvious how fungi can contribute to this, but the normal explanation is that coral reefs can dramatically reduce the damage caused by hurricanes or large waves, so a negative impact of fungi could be **aspergillosis disease of coral**.	16.8

View these data online at these URLs:

http://www.davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/Ch13_01.htm

http://www.davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/Assets/Ecosystem_Services_Resources.html

http://www.davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/Assets/Ecosystem_Services_TABLE-13.1.html