CONVENTION ON INTERNATIONAL TRADE IN ENDANGERED SPECIES
OF WILD FAUNA AND FLORA

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The application of CITES to Fungi and Lichen

1. This document has been submitted by the United Kingdom of Great Britain and Northern Ireland (UK) in relation to agenda item 75[*] on assessment of the practicalities of the CoP12 decision that the Convention applies to fungi.

2. The accompanying report titled ***A Review of Genera of Fungi and Lichens in international trade*** undertaken by the Royal Botanic Gardens, Kew includes an analysis of fungal and lichen species in trade, including the potential threat to the taxa that current trade represents. The report is a preliminary literature-based assessment of fungi and lichen genera which may be at threat from international trade as context for SC78 Doc. 75. It remains for Parties to develop robust proposals for any potential amendments to the CITES Appendices as set out in Article XV and in line with the criteria set out in Res. Conf. 9.24 (Rev. CoP17).

3. Fungi and lichens are eukaryotic higher organisms, comprising the third kingdom of life, alongside flora and fauna. Found on every continent, fungi and lichens have a wide range of uses from culinary, pharmaceutical to fabrication of products. They are highly valuable commodities, and international trade is estimated at billions of US dollars annually.

4. Although some fungi can be cultivated easily, many have specific habitat requirements, are slower growing, or in the case of lichens, require a mutualistic partnership with algae or bacteria. This means that artificial propagation is not always viable and wild harvesting is the only source for some species. Combined with other threats, such as habitat loss, wild sourcing of fungi and lichens could pose a threat to the survival of some species.

5. The review includes selected genera that are potentially traded internationally into or out of the UK and may be threatened by international trade, giving an overview of biological characteristics, primary uses, trade trends and possible threats. The review was formed from available academic literature and trade data from the UN ComTrade Database, and complements recent academic research (Oyanedal ***et al***., 2024; Oyanedal ***et al***., 2022) assessing fungi in trade and international frameworks.

6. The focus of this review is on macroscopic fungi and lichens, of which the fruiting bodies are traded. This does not include fungal inoculants of tree species, such as ***Phaeoacremonium parasitica*** present in Agarwood-producing taxa ***Aquilaria spp.*** or ***Gyrinops spp.***. Additionally, it does not cover fungal and lichen partners that are critical to survival of other CITES-listed species (i.e. mycorrhizal fungi), if the fungus or lichen species in question is not directly traded itself or visible to the naked eye.

7. This review draws on information that has become available since CoP12, providing a more current assessment of fungi in trade and highlighting taxa that could warrant further research and consideration by range states. However, it is worth noting that trade in fungi and lichens is frequently unreported and this review therefore identifies species that may merit further research and consideration as potential candidates for inclusion in CITES.

[*] *The geographical designations employed in this document do not imply the expression of any opinion whatsoever on the part of the CITES Secretariat (or the United Nations Environment Programme) concerning the legal status of any country, territory, or area, or concerning the delimitation of its frontiers or boundaries. The responsibility for the contents of the document rests exclusively with its author.*

Royal Botanic Gardens

Kew

A Review of Genera of Fungi and Lichens in international trade

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Summary Table

Table 1: A summary of the genera included in the report in alphabetical order, their geographical distribution by continent, their primary uses and source codes (W = Wild, A = Artificial propagation), an approximate total international trade volume per annum (kg) based on UN ComTrade Data and key threats facing members of the genus (in descending order of risk).

Genus	Geographical Distribution	Primary Uses	Primary Source Codes	International Trade Volume per annum (kg)	Threats
Agaricus	Global	Food	A	> 500 million	Wild harvesting for international trade
Albatrellus	Asia, Europe, North America	Food	W	Unquantified	Varied across genus
Amanita	Global	Food	W/A	Unquantified	Wild harvesting for domestic trade
Armillaria	Asia, Europe, North America	Food	W	Unquantified	Habitat loss
Auricularia	Global	Food/ Medicine	A	Unquantified	Varied across genus
Boletus	Asia, Europe, North America	Food	W	> 5 million	Varied across genus
Butyriboletus	Asia, Europe, North America	Food	W	Unquantified	Wild harvesting for international trade
Cantharellus	Global	Food	W	> 50 million	Habitat loss
Cordyceps	Asia	Medicine	A	Unquantified	Varied across genus
Craterellus	Global	Food	W	Unquantified	Varied across genus
Fomes	Asia, Europe, North America	Material	W	Unquantified	Varied across genus
Ganoderma	Africa, Asia, South America, Oceania	Medicine	W	Unquantified	Habitat loss Wild harvesting for international trade
Hericium	Asia, Europe, North America	Medicine	W/A	Unquantified	Habitat loss
Hydnum	Global	Food	W	Unquantified	Varied across genus
Inonotus	Asia, Europe, North America	Medicine	W	Unquantified	Wild harvesting for international trade

Lactarius	Global	Food	W	Unquantified	Varied across genus
Lichens	Global	Dyes/Food/ Medicine	W	Unquantified	Habitat loss Wild harvesting for international and domestic trade
Morchella	Asia, Europe, North America	Food	W/A	Unquantified	Wild harvesting for international trade
Ophiocordyceps	Asia	Medicine	W	Unquantified	Wild harvesting for international trade
Tricholoma	Asia, Europe, North America	Food	W	> 500, 000	Wild harvesting for international trade
Tuber	Asia, Europe, North America	Food	W/A	> 1 million	Wild harvesting for international trade Habitat loss

Abbreviations

$	Dollars (United States unless otherwise stated)
€	Euro
£	Pound Sterling
%	Percent
CITES	Convention on International Trade in Endangered Species
cm	Centimetres
CoP	Conference of Parties
FDA	U.S Food and Drug Administration
GDP	Gross Domestic Product
IUCN	International Union for Conservation of Nature Red List of Threatened Species
kg	Kilogram(s)
LANUV	Landesamt für Natur, Umwelt und Verbraucherschutz
NDF	Non-Detriment Finding
UN	United Nations
US	United States of America
UK	United Kingdom of Great Britain and Northern Ireland

Introduction

The international trade of endangered plants and animals from the wild has been regulated since 1975, when the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) came into effect. This agreement between countries, 'Parties', has regulated trade in wild organisms to have mechanisms for sustainable, legal and traceable trade, with the intention of reducing the pressure upon wild species that would otherwise be threatened. However, this only applies if said species are either plants or animals. The third kingdom of multicellular life, Fungi, is currently unrepresented in CITES Appendices.

The elusive nature of fungi may explain their absence from CITES. It was only four years before the establishment of CITES in 1975 that fungi were formally acknowledged as a separate group from plants. The process of widely acknowledging fungi as separate occurred between 1961 and 1971 (Langakawi, 2001; Whittaker, 1969). Most fungi exist as networks of filaments called hyphae, invisible to the naked eye. While many of these fungi manage to escape our detection, some of them produce above-ground macro-structures. Mushrooms, truffles, morels, puffballs, and stinkhorns are all the visible fruiting bodies of often vast fungal networks (mycelia). To add additional complexity, lichens are not true fungi. Lichens are a symbiotic relationship between algae or cyanobacteria that live amongst fungal filaments (Grimm *et al*., 2021). This mutually beneficial relationship results in plant-like structures called thalli (Hawksworth & Grube, 2020), which have commercial applications and cause them to be seen in international trade.

The international trade in edible mushrooms is estimated to be worth approximately $42 billion per annum (Willis, 2018). This market comprises both wild-collected and cultivated mushrooms, the latter of which has been previously estimated to be worth $18-23 billion (Boa, 2004). The most cultivated mushroom genera include *Agaricus*, *Pleurotus*, *Lentinula*, *Auricularia*, and *Flammulina;* which have been estimated to constitute 85% of the world's mushroom supply (Miina *et al.,* 2021; Wang & Chen, 2014). These species are saprobic, meaning that they grow on dead or decaying organic matter such as wood. In contrast, many of the most expensive wild-collected fungi are ectomycorrhizal (Yun & Hall, 2004), growing in symbiosis with plants and acting as extensions of root systems. Therefore, in addition to their economic importance as food and medicine, they have a huge ecological role in maintaining forest health. Another result of this symbiosis is that they are harder to cultivate. This equally applies to lichens, that may have more than two mutualistic partners, making them difficult to artificially propagate.

Because CITES aims to protect wild species that are threatened by international trade and fungi cultivation for many species is challenging, wild-collected fungi species are the primary focus of this review. Some fungal genera that are both ectomycorrhizal and highly internationally traded include *Amanita, Boletus, Cantharellus, Lactarius, Russula, Tricholoma*, and *Tuber* (Boa, 2004; Molina *et al.,* 1993; Pilz & Molina, 1996; Rowe, 1997; Willis, 2018). Fungi within the genera *Morchella* are also highly traded and are often difficult to cultivate, as are *Ophiocordyceps*, a parasitic fungus that has subject to recent analyses assess this trade (Rowe, 1997; Raut *et al.,* 2019; Willis, 2018). These fungi are significant contributors to rural economies around the world, which are sometimes dependent upon them for income (Niego *et al*., 2023). It is therefore important to ensure the sustainability of their trade. There is existing protection in some areas, with FairWild introducing a pilot scheme for certification for fungi in 2021, which ensures sustainable supply through a stringent auditing processing (FairWild, 2024). The trade in the number of species of fungi is predicted to increase with growing demand, further highlighting the need for review (Case *et al*., 2022; Niego *et al*., 2023).

The regulation of fungi and lichens under CITES is a potential opportunity and omission in their conservation, if there are species which meet the CITES listing criteria outlined in Resolution Conference 9.24 (Rev. CoP17). For many plants and animals, conservation efforts have begun only after observing their decline. Observable declines are occurring for some highly traded edible fungi, highlighting the need to consider interventions to avoid irreparable damage due to overexploitation ed, and ensure that fungi populations can remain viable (May *et al.,* 2018*;* Molina *et al*., 2011). Fungi were only recently included on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Mueller, 2017), with 781 species included as of September 2024 (IUCN, 2024). This step towards monitoring global species trends is positive for fungal conservation (May *et al*., 2018). A preliminary review of the application of CITES to fungi in 2001 suggested that the CITES Conference of the Parties should decide on whether the word 'flora' in the title of the Convention covers both Fungi and Plantae (Langakawi, 2001). At the 12th Conference of the Parties (CoP) in 2002, it was agreed that there was no formal intention to exclude fungi, and should species meet the criteria for listing, they could be included (CoP12 Plen. 3 (Rev)). The literature was reviewed for information upon the taxonomy, genus characteristics, status and trends, threats, utilisation and trade, legal instruments, species management and information on similar species for some of the most highly internationally traded fungal genera. This report aims to inform potential future steps in the implementation of fungi within CITES.

The genera selected for in depth analysis were based on the following inclusion criteria:

- whether there is significant trade on international markets recorded through the United Nations ComTrade Database or peer reviewed publications. In some cases where anecdotal evidence suggests there is international trade, or the market is burgeoning, the use of internet search terms was used in lieu of publicly available trade records. This includes whether there is a significant import or export from the UK, as a consideration of UK CITES Authorities.
- whether there are endangered or vulnerable species, as specified by the International Union for Conservation of Nature Red List of Threatened Species ("IUCN") and/or the Global Fungal Red List Initiative in the genus.

<u>Aims and Objectives</u>

The aim of this study is to understand the potential risks associated with international trade of fungi and to increase the evidence base for future decisions on fungi within the CITES framework.

The objectives are as follows:

1. Identify taxa that are currently in trade internationally, including to/from the UK, and their markets
2. Map recent trade fluxes as a predictor of future trends
3. Review the ecological and biological characteristics associated with traded taxa, that influence the risk associated with international trade

Brief Overview of Fungal Taxonomy, Biology and Anatomy

Taxonomy and Biology

Like plants and animals, fungi are complex and (mostly) multicellular organisms (Johnston, 2022). They are genetically more akin to animals (Shalchian-Tabrizi *et al*., 2008), although superficially they seem to have more in common with plants (Johnston, 2022). The phylogeny of fungi is poorly understood, but there are seven phyla recognised (Asiegbu & Kovalchuk, 2021). The most primitive are the Microsporidia, which are single-celled spore-like structures that are part of the kingdom fungi due to the presence of chitin (a tough and pliable polysaccharide) in their reproductive spores (Fadhilah *et al*., 2023). They differ significantly from the other phyla, in that they lack chitin in the mature cell walls, hence they are not considered true fungi (Wijayawardene *et al*., 2020). They are frequently intracellular parasites that break through other cells and engulf the contents (Fadhilah *et al*., 2023).

There are six phyla of true fungi (Naranjo-Ortiz & Gabaldón, 2019), which share the following common traits: cell walls made of chitin-glucan complexes, the requirement for external sources of nutrition (heterotrophy) and cells that contain a single set of chromosomes in their nuclei (haploidy) (Asiegbu & Kovalchuk, 2021; Gleason *et al.*, 2017; Naranjo-Ortiz & Gabaldón, 2019). Note that fungi are not photosynthetic, like plants. Lichens are photosynthetic, but this is due to the other species in their partnership, not the fungal component (see Lichens – page 32).

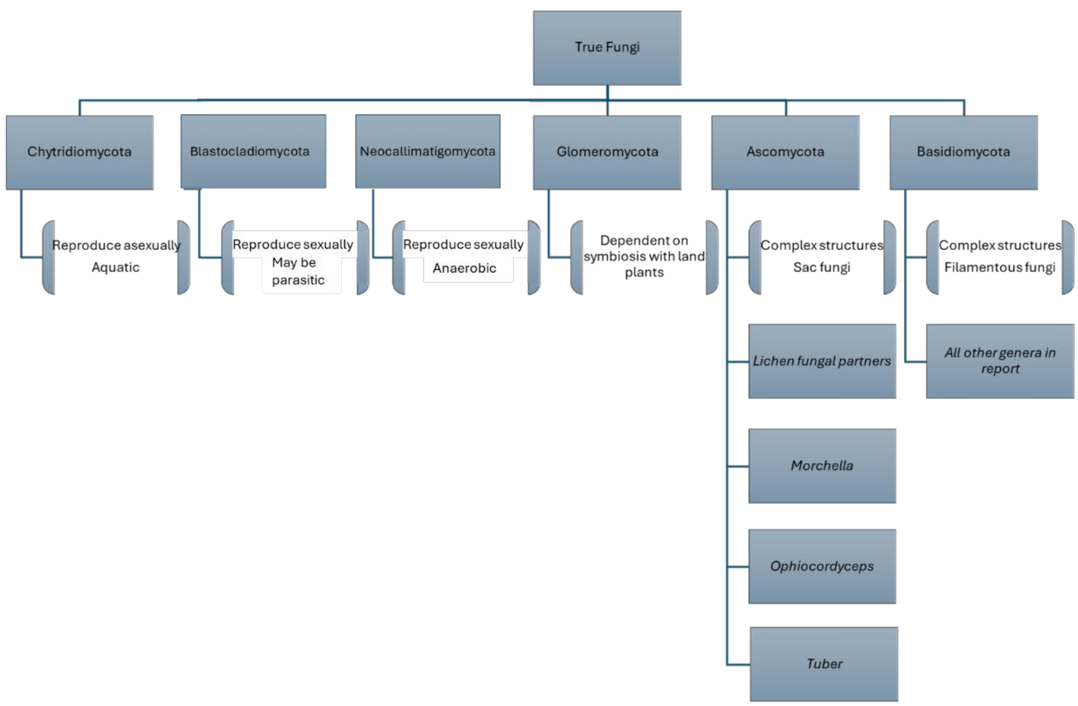

Figure 1: Diagram of fungal taxonomy showing the six phyla of true fungi, from left to right to most complex organism. The fungi detailed in this report are listed under their phyla, note that only genera in Ascomycota and Basidiomycota are represented. Note Basidiomycota may not always be filamentous, and Ascomycota are mostly filamentous fungi.

Chytridiomycota are the earliest known true fungi (Sinha *et al*., 2016), forming simple enclosed structures in which reproductive spores are formed (sporangia) and occasionally root-like secondary structures (Naranjo-Ortiz & Gabaldón, 2019; Sinha *et al*., 2016). They are exclusively aquatic and can be found in open bodies of water, as well as the water layers around soil particles (Sinha *et al*., 2016). Blastocladiomycota are found in complex organisms, that always form symbiotic relationships with plant roots (Asiegbu & Kovalchuk, 2021; Naranjo-Ortiz & Gabaldón, 2019).

The two most complex phyla are the Ascomycota and Basidiomycota, contained within the sub-kingdom Dikarya (Wijayawardene *et al*., 2020). All the species in the report are in these two groups. Ascomycota are typified by their sac-like structures to contain their spores and frequently form cup-like bodies to catch raindrops that splash reproductive spores away from the main body of the fungus (Asiegbu & Kovalchuk, 2021; Naranjo-Ortiz & Gabaldón, 2019). Most edible fungi are in this phylum (Taylor *et al*., 2009).
soil and bodies of water, where they fulfill an important role as degraders of organic matter (Asiegbu & Kovalchuk, 2021; Naranjo-Ortiz & Gabaldón, 2019; Powell, 2017). Neocallimastigomycota are symbionts that cannot tolerate oxygen and are exclusively found in the digestive tracts of animals (Asiegbu & Kovalchuk, 2021; Naranjo-Ortiz & Gabaldón, 2019). Glomeromycota are more

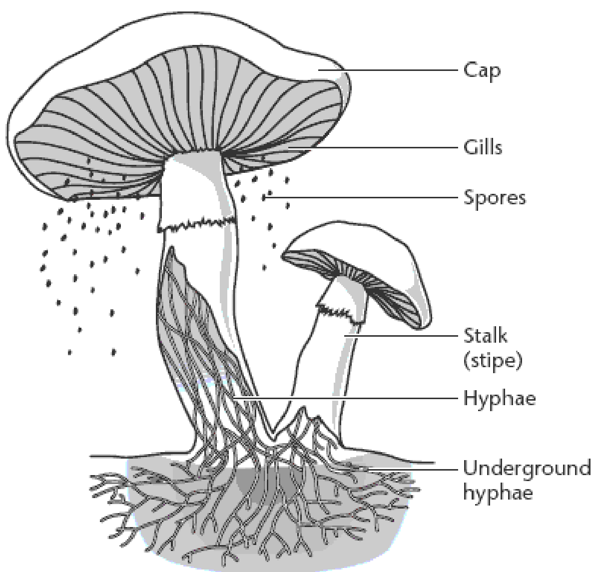

Figure 2: Diagram of fruiting body gross anatomy. (Adapted from Karakaya *et al.,* 2023

<u>Anatomy</u>

Filamentous fungi grow as cylindrical, hair-like structures known as hyphae (Weston & Whittaker, 2004; Zabel & Morrel, 2024). Hyphae are microscopic, measuring micrometers in diameter, but can reach centimeters in length (Weston & Whittaker, 2004). Hyphae can form interconnected networks, collectively known as mycelia (Johnston & Brewer, 2023; Zabel & Morrel, 2024). Mycelia are root-like structures that embed into the substrate of the fungi - such as tree bark or soil - (Johnstone & Brewer, 2023) and absorb organic carbon polymers from the substrate (Johnston & Brewer, 2023). Mycelia can also form aerial macroscopic structures, known as fruiting bodies or sporocarps. These are the archetypal “mushroom” structure but are only a small fraction of the overall fungus, with the embedded mycelium being the largest part, in some species spanning acres (Daley, 2018).

The fruiting body is but one of many reproductive strategies that fungi employ, and is the structure in which sporangia, or spores, are held and dispersed for asexual reproduction (Sundy *et al.,* 2021). The fruiting body is not only the most widely harvested part of Dikarya fungi for human use but is the key method of identifying species outside of molecular analysis (Maurice *et al.,* 2021). It is worth noting that for some Ascomycetes and Basidiomycetes, some 'species' are in fact different reproductive stages of the same organism (Hawksworth, 2011), such as *Beavaria* and *Cordyceps*. In this example the genus *Beavaria* is the anamorph, or asexual stage, forms microscopic, unicellular non-motile spores (Sung *et al.,* 2007). These are significantly morphologically different to the teleomorph, or sexual stage, which are known under the genus *Cordyceps* and form club-like aerial structures (Sung *et al.,* 2007). This system of dual naming was abolished in 2011 but may persist in trade and commercial naming of fungi and may cause confusion for those wishing to review fungal trade (Hawksworth, 2011).

Genera Review

Agaricus

Figure 4: Harvested *Agaricus sylvaticus* in its natural woodland habitat, showing the characteristic pink gills (Digifolia, 2024).

Genus Characteristics

Agaricus spp. are obligate saprophytes – fungi that require dead and decaying matter for their survival (Suzuki & Sasaki, 2019). As such, they are found in a variety of environments where nutrient-rich, decaying organic matter may be found – such as fields grazed by animals and forest floors (Bashir *et al.,* 2021; Jaichaliaw *et al.,* 2021; Oh *et al*., 2021). They all have lamellae, or gills, which are usually white to pink in colour (Fig. 4) and leave characteristic brown spore prints (Jaichaliaw *et al.,* 2021). They can be difficult to tell apart from each other, even when mature (Oh *et al.,* 2021) and immature specimens are frequently confused with toxic *Amanita* species (Wennig *et al.,* 2020). An unregulated market in wild harvested specimens for consumption is therefore not without risk, due to the need for expertise in identification.

Threats

Agaricus spp. do not appear to be under threat from international trade. There are five species of *Agaricus* listed on the IUCN, and the four listed species that are suggested to be used internationally: *A. arvensis, A. bitorquis, A. sylvaticus,* and *A. campestris*, are all listed as being Least Concern with stable populations (Dahlberg, 2019a; Dahlberg, 2019b; Dahlberg, 2019c; Dahlberg, 2019d). Since the species that are internationally traded, such as *A. bisporus* (Fig. 5.), can typically be cultivated with ease, wild populations seem unlikely to be threatened by international trade (Rzymski *et al.,* 2017a; Rzymski *et al.,* 2017b; Willis, 2018).

Figure 5: *Agaricus bisporus* "Portobello" – the Common Button Mushroom commonly seen in retail trade (Shutterstock, 2024).

Utilisation and trade

There are three commonly traded Agaricus species, with one of them being one of the most economically valuable mushrooms worldwide (Rzymski *et al.,* 2017b). This highly traded species is *A. bisporus*, and the other two internationally traded species are *A. arvensis* and *A. subrufescens* (Sonnenberg *et al.,* 2017; Willis, 2018). *A. bisporus* is the fungus most commonly seen in retail in Europe and North America (Ganeshpurkar et al., 2010), and accounts for 35-40% of global edible mushroom cultivation (Rezaeian & Pourianfar, 2016). The average annual consumption of *A. bisporus* in Europe is approximately 2 kg per person. Moreover, the annual crop value of *A. bisporus* is suggested to have exceeded $3.2 billion worldwide in 2009, and data from the UN Comtrade Database suggests that the annual trade at the very least exceeds $1 billion (Tab. 1).

Table 2: United Nations (UN) Comtrade – Exports in 2022. This includes data for fresh or chilled *Agaricus spp.* mushrooms, however there are separate categories for provisionally preserved *Agaricus spp.*, cut or powdered agaricus, and preserved Agaricus. If these categories are included, *Agaricus spp.* trade is shown to be more economically valuable, and China is found to surpass Poland as the largest exporter (China has a trade value of $498,548,293 and a net weight of 196,237,652 kg, whereas Poland has a trade value of $492,560,668 and a net weight of 244835322 kg).

Number	Country	Trade Value ($)	Net Weight (kg)
1	Poland	492,560,668	244,835,322
2	Canada	323,381,304	65,283,521
3	Netherlands	162,458,276	52,379,907
4	Ireland	111,464,136	43,121,800
5	China	35,256,443	18,419,213
6	Mexico	29,203,992	9,466,048
7	Belgium	29,078,893	12,689,082
8	USA	23,030,004	4,931,684
9	UK	21,656,019	10,094,329
10	Lithuania	20,305,511	8,954,704

Table 3: UN Comtrade - Imports 2022. As with the exports, including the other categories of *Agaricus* commodities showed an increased import value, such as an additional import of 48479733 kg of prepared or preserved *Agaricus* into the US, worth $156,663,352.

Number	Country	Trade Value ($)	Net Weight (kg)
1	USA	381,744,774	82,089,726
2	UK	174,900,563	76,444,740
3	Germany	146,415,323	62,869,325
4	France	67,214,609	28,284,049
5	Netherlands	52,918,172	20,563,104
6	Ireland	32,034,231	14,732,886
7	Belgium	29,705,276	14,173,120
8	Sweden	24,928,586	9,733,351
9	Austria	23,518,700	9,426,451
10	Canada	22,445,351	5,082,084

Agaricus species in trade have generally been cultivated with great success, although some of them may also be collected from the wild. *A. bisporus* is the commercially most cultivated mushroom species worldwide (Bashir *et al*., 2021), partially because it is both nutritionally beneficial and relatively inexpensive to cultivate (Rzymski *et al.,* 2017a; Rzymski *et al.,* 2017b; Willis, 2018). It is especially cultivated in the West, and cultivation is also increasing within China (Sonnenberg *et al.,* 2017). In particular, Poland is a big exporter, and it is said to be the origin of 35% of the world's imported *A. bisporus* (Rzymski *et al.,* 2017b).

It has been suggested that *A. campestris* (also known as *A. blazei*) is not commercially cultivated due its fast maturation and short shelf-life, although it may be commercially cultivated in some locations (Dahlberg, 2019c; Dias *et al.,* 2004; Waksman & Nissen, 1932). It is nevertheless a commonly eaten wild mushroom internationally (Dahlberg, 2019c).

Although less commercially traded than *A. bisporus*, other *Agaricus* species are similarly used for food. *A. subrefescens* is a prized gourmet edible that has become cultivated in, commercialised by, and exported from, Brazil. (Kligman, 1943; Llarena-Hernández *et al.,* 2014; Rzymski *et al.,* 2017b; Wisitrassameewong *et al.,* 2012). In addition to Brazil, it is also cultivated in Asia (Rzymski *et al.,* 2017b). In contrast, *A. arvensis* has been much less cultivated. It is commonly collected from the wild, internationally, as it is considered to be one of the most delicious edible fungi (Dahlberg, 2019a; Rzymski *et al.,* 2017b). *A. bitorquis* and *A. sylvaticus* are similarly wild-harvested edible fungi (Dahlberg, 2019b; Dahlberg, 2019c).

In addition to their edibility, *A. bisporus* and *A. subrufescens* are also thought to have medicinal properties. *A. bisporus* has been suggested to have anti-microbial, anti-tumoral, anti-carcinogenic, and antioxidant properties (Gariboldi *et al.,* 2023; Jagadish *et al.,* 2009) and *A. subrufescens* has also been suggested to have antioxidant, anti-tumour, and anti-carcinogenic properties (Endo et al., 2010; Akiyama et al., 2011). In the case of *A. subrufescens,* the US Food and Drug Administration (FDA) has issued warnings that it has been touted as a cancer-cure without sufficient biomedical evidence and can cause liver damage in large quantities (FDA, 2017; Mukai *et al.,* 2006). Despite these warnings, claims such as these have likely added to their commerce (Dias *et al.,* 2004; Leiva *et al.,* 2015; Rzymski *et al.,* 2017b).

Albatrellus

Figure 6: *Albatrellus confluens* in its native forest environment, with the broad, shelf like caps characteristic of bracket fungi clearly displayed (Digifolia, 2024).

Species characteristics

Albatrellus spp. are widely distributed in the temperate forests of the Northern Hemisphere, frequently in association with *Pinaceae spp.,* although whether they are true ectomycorrhizoidal species is unclear (O'Reilly, 2011). They are polypores, fungi that form large fleshy growths with pores or tubes on the underside and are commonly referred to as bracket fungus (Bessette *et al*., 2021). However, unlike most bracket fungi, some species of *Albatrellus* grow directly out of the ground, and not in association with trees (Bessette *et al.,* 2021; O'Reilly, 2011).

Threats

There is little information regarding whether *Albatrellus spp.* are threatened by international trade. Two species of *Albatrellus* have been listed on the IUCN, of which the internationally utilised *A. confluens* (Fig. 6) is one, listed as Least Concern, with a stable population (Dahlberg, 2019c).

Utilisation and trade

There appears to be a lack of information upon the use of *Albatrellus* species in international trade, if such international trade exists. Nevertheless, *A. confluens* is suggested to be used internationally as an edible species, and it contains a potential antitumor natural product (Dahlberg, 2019c). Some other *Albatrellus* species are also edible and can be found in markets (Zheng & Liu, 2008). For instance, *A. ovinus* is a commercially sold species in Finland (Pelkonen *et al.,* 2008), and *A. ellisii, A. confluens, A. dispansus,* and *A. fumosus* are popular edible species for sale in Chinese markets (Zheng & Liu, 2008). *Albatrellus spp.* have been used in traditional Chinese medicine as an anti-carcinogenic agent (Son & Van, 2024), so there is possibly an appetite for international trade in South-East Asian markets and wider Chinese diaspora, but evidence for this is limited.

Amanita

Figure 7: A young specimen of the archetypal toadstool, *Amanita muscaria* with its classic red laccate cap with white scales (Digifolia, 2024)

Genus Characteristics

Amanita species can be found in temperate and tropical regions of Africa, Asia, Australia, Europe, and the Americas (Zhang *et al.,* 2015). *Amanita caesarea* specifically can be found in southern Europe and North Africa, as well as the Balkans, Hungary, India, Iran, China, and Mexico (Zhang *et al*., 2015; Zhou *et al.,* 2023). Similarly, *Amanita muscaria* (Fig. 7) is widespread and can be found in temperate and boreal regions of the northern hemisphere within Europe, North America, and eastern Asia (Wolfe *et al.,* 2010; Zhang *et al*., 2015; Zhou *et al.,* 2023). It has also been introduced into the southern hemisphere, including Australia, New Zealand, South Africa, and South America (Zhang *et al.,* 2015). Some *Amanita* species are fatally poisonous, such as Destroying Angel *(Amanita virosa)* and Deathcap *(Amanita phalloides),* whereas others are edible (Boa, 2004).

For a genus as large as *Amanita*, it is difficult to determine whether the species tends to occupy a continuous or a fragmented distribution. Ocean boundaries prevent the dispersal of *Amanita* species; deserts and mountains also restrict dispersal to a limited extent (Zhang *et al*., 2015). Perhaps most importantly, the ectomycorrhizal nature of *Amanita* means that it is restricted by the distribution of its host plant. (Bruns *et al.,* 2002; Zhang *et al*., 2015; Wolfe *et al.,* 2010). These are commonly Oak trees and conifers, but other species of broad-leaves hardwoods can be colonised (Wolfe *et al.,* 2010). *Amanita caesarea* (Fig. 8) is commonly referred to as Caesar's mushroom, royal amanita, impériale, cesarski, Kaiserling, ovolo, kuqëlorja, Amanite des Césars, or Oronge (Gonçalves, 2019).

Figure 8: A mature specimen of *Amanita caesarea*, the most traded *Amanita* species (Shutterstock, 2022).

<u>Threats</u>

Amanita spp. do not appear to be threatened by international trade, although *A. caesarea* may be threatened by high levels of national utilisation. On the IUCN (IUCN), twenty-six *Amanita* species are listed. Of these, two are Near Threatened, nine are Vulnerable, two are Data Deficient, and thirteen are Least Concern, however none appear to be internationally traded, or threatened by international trade (IUCN, 2022). The highly nationally traded *A. caesarea* has been listed as Least Concern, but it may be threatened by forestry and pollution. There have also been reports of its unsustainable harvesting (Gonçalves, 2019). There is little information to suggest that it is internationally traded in significant quantities, but if it is, this unsustainable harvesting may threaten it.

Amanita caesaria has regional legal protection; notably in Croatia where harvesting and trade has strict procedures and requires registration (Ministarstvo Zaštite Okoliša I Prostornog Uređenja, 2002), Slovenia where the maximum permitted harvest is 2 kg per day per person (Uredba o zavarovanih prosto živečih vrstah gliv, 2011) and Germany where collection for commercial trade is prohibited (LANUV, 2017).

<u>Utilisation and Trade</u>

Amanita spp. are some of the most consumed and traded wild-collected fungi (Willis, 2018), however little information is available upon their international trade, and whether international trade is economically significant. *A. caesarea* is one of the most sought-after edible mushrooms in the Mediterranean and is commercially harvested for local and national trade (Gonçalves, 2019). However, on the IUCN, only national utilisation and trade are suggested. The species is not considered to be internationally traded (Gonçalves, 2019).

While *A. caesarea* appears to be available from a number of online shops, it does not have its own category on the UN Comtrade Database. Similarly, *A. muscaria* is known for its hallucinogenic properties, and it can be found on various online shops, but not on the UN Comtrade Database or seemingly on other databases. Cases such as this highlight the need for greater trade oversight and regulation.

There are around five-hundred described *Amanita* species, and around five-hundred more estimated undescribed species (Zhang *et al*., 2015; Zhou *et al.,* 2023). Out of these species, *Amanita muscaria* products could also be found to be sold online (Boa, 2004; Sitta & Davoli, 2013). A search of “Amanita+muscaria+sale” in any search engine brings up a multitude of specialist and general websites selling dried highly toxic Fly Agaric (*Amanita muscaria).*

Armillaria

Figure 9: An infestation of *Armillaria mellea* on a broad-leaf tree, showing the classic yellow-brown colours and dense clusters (Digifolia, 2024).

Genus Characteristics

Armillaria spp. is a genus of ten species, commonly referred to as Honey Fungi. They are pathogens of trees and shrubs in temperate forests, causing dieback and root rot diseases. They are facultative necrotrophs, meaning they require decomposing material and either can colonise already dead tissues or live tissues, which they then kill (Devkota & Hammerschmidt, 2020). They typically form clusters of yellow-brown fleshy and sticky caps, with narrow stipes (Pegler, 2000). Some species are bioluminescent, producing the phenomena known as “fairy fire” or “foxfire” (Ke & Tsai, 2022).

Threats

It is unclear as to whether *Armillaria spp.* are under threat by international trade, although it seems unlikely. There is one species of *Armillaria* listed on the IUCN, *Armillaria ectypa.* This is Near Threatened and has a decreasing population due to the loss of its niche habitat. *A. mellea,* the species, is not on either the IUCN or the Global Fungal Red List Initiative. The international trade in *Armillaria spp.* does not seem to be significant enough to pose a threat, however more data is needed.

Utilisation and trade

There is little evidence of international trade in *Armillaria spp.*, but some species are consumed as edibles. *A. mellea* and its close relatives are consumed in large quantities in Italy and are one of the few wild mushrooms to be imported brined (Sitta & Floriani, 2008). *A. mellea* is also considered to be edible in other countries, such as Greece, Morocco, and Portugal, as well as in Asia (Erbiai *et al.,* 2021; Lung & Chang, 2011; Ouzouni *et al.,* 2009). Furthermore, in Asia it has been used as a traditional medicine for the treatment of various human diseases, such as headache, insomnia, palsy, and numbness (Lung &

Chang, 2011). In addition to *A. mellea, A. tabescens* is also considered to be a wild edible mushroom in Greece (Ouzouni *et al.,* 2009). Despite the implication of its use as food and traditional medicine, there is not yet enough information to suggest that these uses entail international trade.

There is also a small international trade in selling spore cultures *Armillaria spp.,* as their bioluminescent properties (Fig. 10) are attractive to fungal enthusiasts. This can be found by typing in “Fairy+Fire+Sale” or similar search terms.

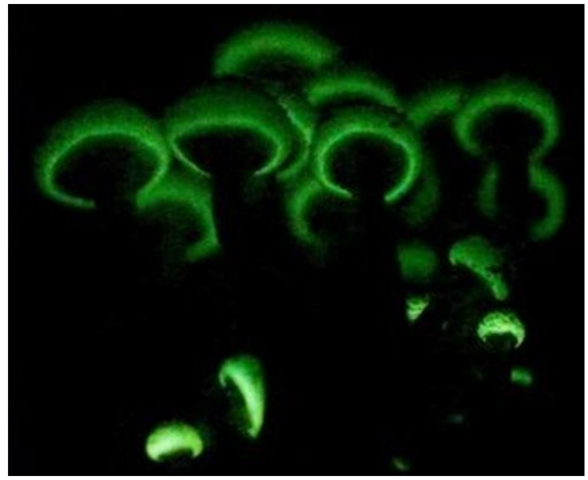

Figure 10: Bioluminescent *Armillaria novae-zealandiae* showing the attractive “fairy fire” phenomenon in the mycelia (Elkhateeb & Daba, 2022).

This appears to be limited to Amazon and Etsy, who have no regulation on non-psychoactive mushrooms. Some sellers specifically state that the cultures have been artificially propagated, but with others it is unclear. The quantities in trade are typically small in both number of specimens and volume of culture, and not likely to be detrimental to wild populations.

Auricularia

Figure 11. *Auricularia heimeur* on a tree branch, clearly displaying the unique jelly-like texture and folded appearance that is typical of the genus (Digifolia, 2024).

Genus Characteristics

Auricularia is a genus of approximately fifty species of saprophytic fungus (Wu *et al.,* 2014), always found growing on trees (Shevchuk *et al.,* 2023). They are easily identified by their unique jelly-like texture and wrinkled, ear-like appearance (Fig. 11) that gives rise to their name (Chen *et al*., 2021). They range from brown to black in colour (Chen *et al.,* 2021; Shevchuk *et al.,* 2023) and are widely distributed in both temperate and tropical forests (Wu *et al.,* 2024).

Threats

There is not enough evidence to suggest whether Auricularia spp. are threatened by international trade. There are no species of *Auricularia* listed on the IUCN, however four species have been proposed for future listing on the Global Fungal Red List Initiative. Nevertheless, while there appears to be very little information regarding threats to *Auricularia spp.*, their widespread cultivation, particularly in mainland China (Bai *et al.*, 2014; Lu *et al.*, 2017; Zhang *et al.*, 2018), suggests that wild specimens are less threatened by trade.

Utilisation and trade

Many species of *Auricularia* are economically important edible mushrooms, and they are widely collected, cultivated, and consumed in a range of countries, including China, Thailand, Korea, Vietnam, Japan, and New Zealand (Kadnikova, 2015; Miao *et al.,* 2020; Wu *et al.*, 2014; Yuan *et al.*, 2019). China is the largest producer of *Auricularia*, accounting for over 90% of its worldwide production (Miao et al., 2020). The main species to be cultivated are *A. heimeur* (historically referred to as *A. auricula-judae*) and *A. polytricha* (Fig. 12), with the former being the most common and popular species.

Figure 12: Wild specimens of *Auricularia polytricha*, the second most traded species in this genus (Digifolia, 2024).

In 2013, 4.75 billion kilograms of *A. heimeu*r alone was produced in China. This had an economic value of around US $4 billion (Kadnikova, 2015; Miao *et al.,* 2020; Wu *et al.*, 2014; Yuan *et al.*, 2019). *Auricularia* have been cultivated for over 1,000 years, indicating their ingrained gastronomic importance (Wu *et al.*, 2014).

Fruiting bodies have been used in traditional medicine, and medical research has shown that they possess a range of beneficial health effects. In Chinese traditional medicine, *A. heimeur* is believed to be a source of anti-tumour compounds and has also been used to treat sore throats and tonsilitis (Kadnikova, 2015; Miao et al., 2020). Moreover, the benefits of *A. heimeur* have been evidenced by medicinal studies. It has been suggested to have anti-carcinogenic, cholesterol-lowering, anticoagulant, antioxidant, immunomodulatory, anti-inflammatory, anti-aging, blood sugar-lowering, and antimicrobial activities (Wu *et al.*, 2014; Yuan *et al.*, 2019). It has also been suggested that the fungus contains compounds preventing thrombosis and that reduce cytotoxicity, as well as that its polysaccharides have are bioactive components (Miao et al., 2020; Kadnikova, 2015).

Boletus

Figure 13: Wild harvested *boletoid species* showing the typical spongy undersides characteristic of the genus (Digifolia, 2024).

Genus Characteristics

Boletus - or porcini - group is distributed throughout the Northern Hemisphere. Boletes are obligate ectomycorrhizal mutualists, meaning they are dependent on colonising the outer surface of plant roots for their survival (Tan *et al*., 2024). This means their distribution is limited to that of their host plants (Dentinger *et al.,* 2010), typically *Fagaceae, Betulaceae and Pinaceae* families (Dentinger *et al.,* 2010; Hall *et al.,*1996; Tan *et al*., 2024). Boletes are native to the temperate zones of the Northern Hemisphere, but some species have been introduced to Australia, North Africa (*B. edulis*) and South Africa (*B. reticulatus*), mostly accidentally through association with their host plants (Feng *et al.,* 2012; Hall *et al*., 1996). They are characterised by their convex caps and spongy undersides (Fig. 13), where they have pores and tubes instead of gills (Lannoy & Estadès, 2001).

Threats

Boletus spp. do not appear to be under threat from international trade. There are twelve *Boletus spp.* listed on the IUCN. Of these, seven are Least Concern, three are Near Threatened, one is Endangered, and one is Data Deficient (IUCN, 2022). The internationally traded type species, *Boletus edulis*, is listed as Least Concern and as having a stable population trend (Dahlberg, 2019f). It is said to have no major threats, and to be commonly found in a variety of human-related habitats (such as plantations and parks). Two other internationally traded species, *B. reticulatus* and *B. pinophilus*, are similarly listed as Least Concern and as having stable population trends (Dahlberg, 2019g; Dahlberg, 2019h). Another edible mushroom, *B. aereus* has not been assessed, although it is a popular species in the culinary industry across Europe (Sitta & Floriani, 2008).

Utilisation and trade

Boletus spp. are some of the most consumed and traded wild-collected fungi species (Cai & Vidale, 2011; Catcheside & Catcheside, 2012; Wang & Chen, 2014; Willis, 2018). The annual worldwide consumption of porcini is estimated to be between 20,000 and 100,000 tons and is estimated to have a global market value of over $250 million (Catcheside & Catcheside, 2012; Dentinger *et al.,* 2010; Wang & Chen, 2014). *B. edulis* (Fig. 14), *B. pinophilus*, *B. reticulatus*, *B. aereus* are internationally traded and have a significant economic worth (Cai & Vidale, 2011; Catcheside & Catcheside, 2012; Dahlberg, 2019f; Dahlberg, 2019g; Dahlberg, 2019h; Dentinger et al., 2010; Wang & Chen, 2014).

Figure 14: *Boletus edulis* – descriptively known as the Penny Bun – with it's slightly sticky cap. This is the most widely traded *Boletus* species (Digifolia, 2024).

Europe is the biggest international trader of Boletus, with Italy dominating trade, importing huge volumes from China, eastern Europe, and Southern Africa (Tabs. 3 and 4). Beyond Europe, *B. edulis* has been introduced into Southern Africa and has since garnered a small export market (Boa, 2004). The trade in *Boletus* is driven by their use as food. They are sold fresh, dried, pickled, brined, or canned. This is partly because the availability of fresh specimens is seasonal (Sitta & Floriani, 2008). *Boletus spp.* in trade are wild collected. While they have been cultivated in lab-scale quantities in the past, mycorrhizas often collapse once infected plants are transferred into unsterile media (Wang & Chen, 2014).

Table 4: The top ten exporters of Boletus in 2022, according to the UN Comtrade Database (Accessed: 14/09/2023). Czechia and Austria also had exports in the hundreds of thousands, and further countries had exports in less economically significant amounts.

Number	Country	Trade Value (US$)	Net Weight (kg)
1	Romania	21,317,952	2,659,865
2	Croatia	4,729,235	585,242
3	Serbia	2,779,144	326,832
4	Italy	2,393,236	179,502
5	Spain	2,176,513	212,337
6	France	2,076,130	150,754
7	Bulgaria	1,723,969	192,831
8	Montenegro	941,955	142,454
9	Germany	930,950	63,953
10	Slovenia	860,380	91,426

Table 5: The top ten importers of Boletus, according to the UN Comtrade database (Accessed: 14/09/2023). Australia, Luxembourg, Czechia, and Canada also imported in the hundreds of thousands. Further countries also imported at less economically significant levels.

Number	Country	Trade Value (US$)	Net Weight (kg)
1	Italy	28,261,233	3,424,835
2	Switzerland	3,220,635	155,277
3	France	2,630,457	257,202
4	Spain	2,544,794	386,033
5	Germany	1,995,322	145,063
6	Austria	1,559,899	177,766
7	Japan	885,122	20,684
8	Slovenia	797,652	112,042
9	Belgium	552,882	156,003
10	Romania	533,148	35,618

Butyriboletus

Figure 15: *Butyriboletus regius* showing similar morphological characteristics to *Boletus,* with the spongy undersides. The primary distinguishing feature from *Boletus* is the butter-yellow stipe, clearly visible in these wild specimens (Shutterstock, 2024).

Genus Characteristics

Commonly known as Butter Boletes, *Butyriboletus* is a recently described genus, determined to be genetically distinct from *Boletus* in 2013 (Nuhn *et al*., 2013). This genus comprises twenty-eight ectomycorrhizal species, all of which are identifiable as *Butyriboletus* by their buttery-yellow stipe and fleshy undersides (Fig. 15) (Arora *et al*., 2014) from which they derive their name, and the presence of pores instead of gills that turn blue when injured (Janda *et al*., 2019). They are predominantly distributed in the Northern Hemisphere (Arora *et al*., 2014) and typically found in forests (Janda *et al*., 2019).

Threats

There are seven species of *Butyriboletus* on the IUCN. All are Least Concern or in the preliminary stages of listing, except *Butyriboletus loyo,* which is Endangered because it has a decreasing population, and is at major threat from over-exploitation for human consumption (Furci, 2019; IUCN, 2024). It is often harvested while it is immature, and it is also often harvested with large amounts of mycelium attached to it (IUCN, 2024).

Utilisation and trade

There appears to be very little data upon the international trade in *Butyriboletus,* if an international market does exist. Nevertheless, it has been suggested that several *Butyriboletus* species are sold in markets in Europe, the western United States, China, Japan, and Mexico (Arora *et al*., 2014). *B. loyo* is used in local and national trade but not in international trade (IUCN, 2024), and *B.*

roseoflavus is reported to be an economically valuable species, as an edible mushroom popular in South China (Arora *et al*., 2014; Li *et al*., 2014) but with limited evidence of international trade.

Cantharellus

Figure 16. Harvested *Cantharellus lateritius* var. *colombiana* – commonly known as the Smooth Chantarelle – showing the characteristic fluted shape and distinct ridged gills (Digifolia, 2024).

<u>Genus Characteristics</u>

There are multiple names for *Cantharellus* species (Pilz *et al*., 2003). The genus is broadly referred to as chanterelles (Fig. 16), with some species having common names that are reflective of this (Antonelli *et al*., 2023; Arora & Dunham, 2008; IUCN, 2024). Yellow and Golden Chanterelles refer to *Cantharellus cibarius*, as well as allied species or potentially other species of medium-sized to large, yellow-orange chanterelles (Arora & Dunham, 2008; Muszyńska *et al.,* 2016). White chanterelles are *Cantharellus subalbidus* (IUCN, 2024). The Pacific golden chanterelle refers to *Cantharellus formosus* (IUCN, 2024).

Cantharellus spp. are ectomycorrhizal, and have host trees in Asia, America, Africa, and Europe (Muszyńska *et al.,* 2016). *C. cibarius*, the internationally traded type species, has been reported from around the world (Arora & Dunham, 2008). This includes countries such as France and Poland, however a scientifically peer-reviewed, comprehensive distribution map of the species does not appear to be available (Arora & Dunham, 2008; Muszyńska *et al.,* 2016). There has also been a suggestion that some of the chanterelles ascribed to being *Cantharellus cibarius* are actually different species, and thus that the distribution of *C. cibarius* may not be as extensive as is often thought. It is certainly present within Europe (Arora & Dunham, 2008; Buyck *et al.,* 2019; Muszyńska *et al.,* 2016; Ogawa *et al.,* 2018 Pilz *et al.,* 2003). Other internationally traded chanterelles, *Cantharellus subalbidus* and *Cantharellus formosus*, can be found on the Western coast of America, and in Canada (IUCN, 2024). There does not appear to be any specific information upon the level of fragmentation of *C. cibarius* (Fig. 17)*, C. subalbidus*, and *C. formosus* populations, although one study found that dispersal was restricted in *C. formosus* (Dunham *et al.,* 2006).

Figure 17: *Cantharellus cibarius*, the archetypal Golden Chantarelle and one of the most commonly traded species in this genus (Shutterstock, 2022).

Being ectomycorrhizal, *Cantharellus spp.* are always found in association with host trees, such as oaks, birch, beech, chestnut, Douglas-fir, hemlock, spruce, fir, and pine (Muszyńska *et al.,* 2016; Pils *et al*., 2003). Chanterelles have a very broad host range; the golden chanterelle alone can form associations with trees in fourteen diverse genera (although the golden chanterelle itself may not be a single species) (Pilz *et al*., 2003).

<u>Threats</u>

There is no convincing evidence for or against Cantharellus being threatened by international trade. On the IUCN, fifty-two Cantharellus species have been listed. Of these species, two are Vulnerable, nineteen are Data Deficient, and thirty-one are Least Concern (IUCN, 2022). While the internationally traded *C. cibarius* has not yet been assessed under the IUCN, the traded *C. subalbidus* is listed as Least Concern with a stable population trend, and *C. formosus* is listed as Least Concern with an increasing population trend (Siegel, 20201b; Siegel, 2021d). Although there seems to be little threat from trade to *Cantharellus spp.*, there have been concerns of overexploitation.

The production and harvest of chanterelles has seen a decline in Europe, for instance, and one prominent example of this has been the 60% decrease in the number of locations where chanterelles fruit in the Netherlands within twenty years (Pilz *et al.,* 2003; Rowe, 1997). Similarly, in North America, the 1995-2005 trade data for the European Union markets indicate a slight overall decline in the value and volume of Canadian chanterelle exports, which ranged from $1-5 million annually (Ehlers & Hobby, 2010). Due to a decline in mushrooms and their habitats within Europe, a significant import market has developed, and chanterelles have been exported from the North American Pacific Northwest to meet demands (Pilz *et al.,* 2003).

While it is possible that chanterelle exploitation has impacted levels of harvest, this is still unclear. The relationship between a decline in chanterelle fruiting bodies and the health of the host tree is also unclear (Norvell *et al.,* 2016). A study of the impact of harvesting on a chanterelle population over ten years in the USA found no declines in productivity. Instead, trampling greatly affected chanterelle fruiting, possibly due to the damage of fruiting body primordia (Rowe, 1997). This has led to the hypothesis that the pre-fruit body primordia are destroyed due to trampling, but that the mycelium itself is not permanently damaged (Egli *et al.,* 2006).

Similarly, a Swedish study observing the intensive harvesting of fruiting bodies from a restricted locality of *C. cibarius* over forty years was unable to find any impacts upon productivity, a study in Switzerland over twenty-nine years found no impact on fruiting body and fruiting species numbers, and a shorter study in Oregon also found no statistically significant impacts (Arnolds, 1991; Egli *et al.,* 2006; Norvell *et al.,* 2016). However, whilst picking decreased chanterelle productivity, it may not have impacted the chanterelle mycelium. Moreover, if the chanterelle mycelium did decrease, there is insufficient evidence as to whether the host trees would be threatened or whether other species might take the role of the chanterelles (Norvell *et al.,* 2016). Some clearer threats to chanterelles and their habitats include air pollution, clearcutting, short timber rotations, and depletion of forest soil litter layers. Further, it has been suggested that the large annual variability in fruit body production due to other factors is more important than the impact of harvesting and trampling (Egli *et al.,* 2006; Ehlers & Hobby, 2010; Rowe, 1997).

Chanterelles are commonly wild-collected and there are two techniques in use: pulling or cutting. Current studies suggest there is little difference between the two techniques in impact (Egli et al., 2006; Norvell et al., 2016). Overall, the main threat to *Cantharellus spp.* in relation to their trade is due to trampling during collection. Moreover, the long-term impact of this upon *Cantharellus* populations and their symbionts requires further study.

<u>Utilisation and trade</u>

Cantharellus spp. are some of the most consumed and traded wild collected fungi (Willis, 2018). They are predominantly used in cuisine, but potentially also for their medicinal value (Zhang, M., *et al.,* 2022b; Zhang, Y., *et al.,* 2022;). Chanterelle fruiting bodies can be prepared by frying, marinating, cooking, freezing, and drying (Muszyńska *et al.,* 2016). They are typically sold either fresh, dried, or pickled in brine (Persson, 1997). *C. cibarius*, the golden chanterelle, and its allied species are particularly subject to international trade (Danell & Camacho, 1997; Muszyńska *et al.,* 2016). *C. subalbidus* and *C. formosus* are also highly prized edible species that are internationally traded, as are *C. roseocanus*, *C. cascadensis*, and *C. miomboensis* according to the IUCN (Ogawa *et al.,* 2018; Siegel, 2021a; Siegel, 2021b; Siegel, 2021c; Siegel, 2021d; Westrip, 2022).

Europe and North America appear to be the main regions that are involved in the international trade of *Cantharallus*. According to the UN Comtrade database, Lithuania and the Netherlands are the biggest exporters of chanterelles, and Germany and Lithuania are the biggest importers of chanterelles (Tabs. 5 and 6). The Pacific Northwest of the United States are also notably involved in the chanterelle industry (Egli *et al.,* 2006). Worldwide chanterelle production has been estimated to be worth about $1.67 billion annually. Moreover, this has been predicted to increase (Arora & Dunham, 2008; Egli *et al.,* 2006; Ogawa *et al.,* 2018). This may make *Cantharellaceae* a candidate for regional, family listings.

Table 6: The top ten exporters of Cantharellus chanterelles, according to the UN Comtrade Database. Slovenia, Latvia, the USA, Bosnia Herzegovina, Spain, Estonia, and Morocco also exported hundreds of thousands of $ of chanterelles, and further countries engaged in globally insignificant levels of export.

Number	Country	Trade Value (US$)
1	Lithuania	21,131,599
2	Netherlands	7,243,501
3	Portugal	3,448,976
4	Romania	2,673,692
5	Belgium	2,618,927
6	Türkiye	2,469.698
7	Germany	2,021,441
8	Serbia	1,908,927
9	Austria	1,817,931
10	Bulgaria	1,749,138

Table 7: The top ten importers of Cantharellus chanterelles, according to the UN Comtrade Database. Slovenia, Japan, Finland, Slovakia, Bulgaria, Luxembourg, and Czechia also imported hundreds of thousands of dollars of chanterelles, and further countries engaged in globally insignificant levels of import.

Number	Country	Trade Value (US$)
1	Germany	20,598,004
2	Lithuania	14,118,394
3	Austria	8,920,003
4	France	7,809,468
5	Italy	4,627,494
6	Switzerland	4,612,690
7	Belgium	3,263,483
8	Netherlands	2,139,713
9	Norway	1,305,138
10	USA	1,267,692

Cordyceps

Figure 18: Wild *Cordyceps militaris,* with the classic finger like projections (Digifolia, 2024).

Genus Characteristics

Cordyceps is a large and diverse genus, with over six-hundred species, predominantly found in Asia (Sung *et al.,* 2007). They are identifiable by their elongated, cylindrical structures and soft, fleshy aerial tissues (Panicker, 2017; Sung *et al.,* 2017). *Cordyceps spp.* are noted for their lifecycle; the majority are obligate, entomopathogens – meaning they must parasitise insects and arthropods (Nicoh, 2000; Fernandes *et al*., 2012). In warm and damp conditions, spores land on the cuticle of insects, which they then breakdown through enzyme action, to reach the body cavity. Once in, fungal cells proliferate and eventually kill the host, bursting through the cuticle with finger like projections (Fig. 18) (Nicoh, 2000; Fernandes *et al*., 2012).

Threats

There does not appear to be enough information to determine whether *Cordyceps spp.* are threatened by international trade.

There are two species of Cordyceps listed on the IUCN, *C. hauturu* and *C. kirkii* – both of which are listed as Data Deficient, and as having unknown population trends (IUCN, 2022). *C. hauturu may have* medicinal, or nutraceutical use and could be under threat if such uses are found (Buchanan, 2019). *C. militaris*, the most widely internationally traded species of *Cordyceps*, has not been published on the IUCN or on the Global Fungal Red List Initiative. However, this species seems less likely to be threatened by international trade because it is widely cultivated (Shrestha *et al.,* 2012).

Trade and utilization

Cordyceps spp. are widely traded for their use in traditional medicine and in nutrition. They have been used in this way for almost 200 years (Lu *et al.,* 2019). *C. militaris* is an important traditional medicine, and it is sold in drugs and health food products in China and South-East Asia (Das, 2010; Lu *et al.,* 2019; Nxumalo, 2020; Shrestha *et al.,* 2012). Worldwide, it has been rising in popularity (Lu *et al.,* 2019). It is sometimes used as a substitute for the Caterpillar Fungus, *Orphiocordyceps sinensis*, which is also in high demand (Shrestha *et al.,* 2012).

While *C. militaris* is the main species of *Cordyceps* in trade, and perhaps the only one that is commercially cultivated, a number of other species are either traded in small quantities or show potential for trade. *C. cicadae*, for instance, is one of the oldest and most well-known traditional Chinese medicines. It has a much smaller market than *C. militaris*, but it is derived to make Cikaria, which is sold as a health supplement in Sweden (Nxumalo, 2020). *C. sobolifera, C. ophioglossides* and *C. militaris* are all used for tonics and therapeutic drugs (Tuli *et al*., 2014). The biological properties of *C. gunnii* and *C. cicadae* indicate that they could be used similarly to *C. militaris* as substitutes for *O. sinensis* (Das *et al.,* 2010; Zhang *et al.,* 2022). Generally, the *Cordyceps spp.* in trade appear to be of cultivated origin. The cultivation of *C. militaris* has been widely explored, so it can be cultivated on a large-scale, and it can be cultivated within a variety of media (Lu *et al.,* 2019; Nxumalo, 2020; Shrestha *et al.,* 2012). Increasing popularity over the last decade has driven the prices high, with reports of specimens reaching as much as $20,000 per kg on some international markets (Panicker, 2017). This suggests that, combined with increasing biomedical research into the properties of *Cordyceps spp.,* there is likely to be increased international trade in this genus.

Craterellus

Figure 19: *Craterellus falax* in a dense bed of moss, showing the characteristic steep funnel shape of the genus (Digifolia, 2024).

Genus Characteristics

Closely related to *Cantharellus spp.*, *Craterellus* is a genus of approximately fifty known species (Dalhman *et al.,* 2000), all of which are considered edible (Hall *et al*., 2023). Similar in appearance to *Cantharellus*, and also broadly referred to as Chantarelles, they are distinguishable by their hollow stipe and funnel-shaped as opposed to the flatter, trumpet-shape of *Cantharellus* (Dahlman *et al,* 2000; O'Reilly, 2011). They are ectomycorrhizal, forming species specific associations with *Betulaceae, Fagaceae, Juglandaceae, Pinaceae* and *Saliaceae* (Hall *et al.,* 2023). Species are globally distributed in temperate and tropical forests (IUCN, 2024).

Threats

Craterellus spp. do not appear to be threatened by trade. There are three *Craterellus spp*. listed on the IUCN. Of these, two are Least Concern and the other is Data Deficient. No decline of *C. calicornucopioides,* due to current harvest practices, has been recorded (IUCN, 2024). There are also over fifty species of *Craterellus* listed on the Global Fungal Red List Initiative.

Utilisation and trade

Some *Craterellus spp.* are used for food, but this appears to be mainly local or national, rather than international. The main *Craterellus spp.* to be used for food are *C. calicornucopioides* and *C. tubaeformis* (IUCN, 2024). *C. cornucopioides* are locally bought for €4-7 per kg in rural Finland and *C. tubaeformis* is harvested in Canada, Norway, and Sweden, although trade data is not obtainable for these markets (Cai *et al*., 2011; Svanberg & Lindh, 2019; Svanberg & Løvaas, 2023). Despite most trade in *Craterellus spp.* being seemingly local, it has been suggested that *C. cornucopioides* is exported from Turkey, fresh, dried, or frozen, and that it is of high edible quality and economic importance (Bulam *et al.,* 2018). However, it is unclear if these exports are of wild or artificially propagated origin, with Hall *et al.,* (2023) stating that the obligate ectomycorrhizal nature of *Craterellus*, and extreme host-specificity, makes them difficult to cultivate and increasingly the likelihood of wild harvest.

Fomes

Figure 20: Wild harvested *Fomes sp.* with the clear hoof-like shape characteristic of the genus (Digifolia, 2024).

Genus Characteristics

Fomes is a parasitic genus of fifty-nine species, characterised by distinctive hoof-shaped fungi that attach directly to tree bark (Schwarze *et al*., 2000). Forming large and sturdy caps with hard, smooth crusts, *Fomes spp.* digest the sap- and heartwood, causing white rot which ultimately kills the host (Tomšovský *et al*., 2023; Schwarze *et al.,* 2000). The fungus can continue to survive on the decaying wood. *Fomes spp.* are globally distributed, found in both broad-leafed and coniferous forests, with the commercially important *Fomes fomentarius* being found widely distributed across the northern hemisphere, with a slight preference for the *Fagaceae* family, but frequently found on a variety of other species (Dyson *et al.,* 2024; Tomšovský *et al*., 2023).

Threats

There is a marked lack of information regarding distributions of *Fomes* spp., both at national and international levels. There is only one species of *Fomes* on the IUCN, *Fomes fasciatus,* which is currently undergoing review (IUCN, 2024). *Fomes fomentarius* is described as common and widespread, with no major concerns about the global population (Dyson *et al.,* 2024; Kibby, 2003).

Utilisation and trade

Fomes fomentarius has multiple uses as the spongy material Amadou (Fig. 21). Amadou is prepared by pounding thin strips of fungus and is commercially used as a drying agent (specifically for fishing flies) and a fire-starting agent.

Figure 21: Amadou “leather” made from *Fomes fomentarius* (FlyMaterial, 2024).

It is gaining wider economic significance as a felt-like material, often marketed as “vegan leather” (Klein, 2018; Pegler, 2001). A brief search for “Amadou+for+sale” online will bring up multiple marketplaces, selling both raw Amadou sheets and finished products. These can be imported into the UK, predominantly from Romania, but also from other countries in Europe, the USA and Australia.

There is rarely reference to where they source *F. fomentarius.* Although there are publications and patents that testify to easy cultivation of this species on lignin- and glucose- rich media (Cotter, 2015; Henning *et al*., 2022; Pohl *et al*., 2022), it is not clear if these are commercially viable or used in industry at all, especially as these are relatively new methods. At present it is likely that *F. fomentarius* specimens are wild harvested. With the decreasing appetite for animal leather and plastic-based vegan leather (Klein, 2018), it is likely that sales of Amadou will increase.

Ganoderma

Figure 22: *Ganoderma multiplicarum* at the base of tree (Digifolia, 2024).

Genus Characteristics

Ganoderma is a genus of approximately eighty species of saprophytic bracket fungus (Kirk *et al*., 2008). Globally distributed, they are commonly found in tropical regions (Kirk *et al.,* 2008, Mawar *et al*., 2012), where they cause significant economic losses for forest risk commodity species, such as cacao and oil palm (Bong *et al*., 2012). *Ganoderma spp.* parasitise and break down the lignin and cellulose structures of trees, causing white rot disease (Mawar *et al*., 2020). They are characterised by thick and smooth surface, with cork-like flesh (Fig. 22) (Ćilerdžić, 2018).

Threats

Ganoderma spp. do not appear to be threatened by international trade, although there appears to be little information addressing their conservation. Eleven species of *Ganoderma* are listed on the IUCN (IUCN, 2024), of which two are endangered. *Ganoderma*, *G sp. nov. 'Awaroa'* is endemic to New Zealand and feared extinct as no new specimens have been found since 1972 (Hitchmough, 2002). *Ganoderma valesiacum* is found only in the Alps and grows specifically on *Larix spp.* (Larch), making it highly vulnerable to species decline through habitat degradation. Both endangered species are considered a "look-alike" for the medicinal *Ganoderma lucidum and* are threatened by sampling as a nutraceutical, especially *G.*

valesiacum (Buchanan & Cooper, 2019; IUCN, 2024). This indicates that wild populations are possibly under threat from international trade. The most internationally traded *Ganoderma spp., G. lucidum*, is sourced from cultivated stock (Bijalwan *et al.,* 2020; Zhou *et al.,* 2011).

Utilisation and trade

Some species of *Ganoderma* are highly internationally traded for use in traditional medicine and nutrition. Laccate (shiny topped) *Ganoderma* species form a major industry in Asia, where one or more species are marketed as lingzhi or reishi (Buchanan & Cooper, 2019). *G. lucidum* is one of the most popular and important medicinal mushrooms (Bijalwan *et al.,* 2020). It has been used in traditional Chinese medicine in Asian countries for thousands of years, including within China, Japan, and Korea (Baby *et al.,* 2015; Bijalwan *et al.,* 2020; Boh *et al.,* 2007; Paterson, 2006; Sliva, 2003). Here, it was used to preserve vitality and promote longevity. It is suggested to treat cancer, asthma, diabetes, allergies, arthritis, hypertension, inflammation, and a range of other conditions (Paterson, 2006; Sliva, 2003). The use of *G. lucidum* in traditional medicine has prompted research into its biological properties, and it has since been found to have a range of benefits. *G. lucidum* has been shown to induce apoptosis, inhibit cell proliferation, and to suppress the migration of prostate cancer cells (Paterson, 2006). It has been found to have immunomodulatory, cardiovascular, respiratory, antihepatotoxic, and central nervous system effects (Boh *et al.,* 2007; Sliva, 2003).

The many suggested health benefits of *Ganoderma spp.* medicinal and nutraceutical products have resulted in its large economic value (Buchanan & Cooper, 2019). It is traded as extracts and dried powders, and these are used as dietary supplements worldwide (Baby *et al.,* 2015; Paterson, 2006; Bijalwan *et al.,* 2020). Moreover, the *Ganoderma spp.* business is growing, and the annual sale of products derived from *G. lucidum* has previously been estimated to be more than $2.5 billion (Baby *et al.,* 2015; Bijalwan *et al.,* 2020). There is conflicting information about the status of wild populations, with some authors describing it as rare in nature (Boh *et al.,* 2007; Sliva, 2003), whereas others describe it as widespread and abundant (Loyd *et al*., 2018). However, given the size of the market, artificial cultivation is essential to meeting demands (Boh *et al.,* 2007). It is thus intensively cultivated around the world, particularly in South-East Asia (Bijalwan *et al.,* 2020; Zhou *et al.,* 2011).

Hericium

Figure 23: *Hericium erinaceus* attached to a tree trunk, showing the long , draping fruiting bodies characteristic of the genus (Digifolia, 2024).

Genus Characteristics

Hericium spp., commonly known as Lions' Mane fungus, is a genus of edible saprophytes (Cannon & Kirk, 2007; Ellis & Ellis, 1990). They are easily identified by the white spiney formation of their fruiting bodies (Fig. 23) (Ellis & Ellis, 1990; Volk, 2003). They are widely distributed in the Northern Hemisphere, preferring dark and undisturbed areas of deciduous and coniferous forests (Canon & Kirk, 2007).

Threats

Hericium spp. Do not appear to be under threat from international trade, owing to their ease of cultivation. There are five *Hericium* species listed on the IUCN. The commercially traded *H. erinaceus* is Least Concern, despite its decreasing population (Kalucka & Olariaga Ibarguren, 2019). However, it is also one of only four species of fungi to be listed under Schedule 8 of the Wildlife and Countryside Act, 1981 in the UK. The main threats to *H. erinaceus* include habitat loss due to logging and land use changes, as well as the heavy harvesting of fruiting bodies (Kalucka & Olariaga Ibarguren, 2019). Little specific information appears to be available on the impact of harvesting on wild *H. erinaceus* populations.

Utilisation and trade

H. erinaceus appears to be an economically significant species of fungi. It is the most commercially traded species in its genus, due to its use in food and as a pharmaceutical (Kalucka & Olariaga Ibarguren, 2019). It is an edible medicinal mushroom, and a delicacy for food supplementation, often used in products to treat epigastric pain caused by chronic superficial gastritis, gastric ulcer, or atrophic gastritis. *H. erinaceus* also has anti-tumour and immunomodulatory activities, and it promotes learning and memory by protecting neuronal cells (He *et al.,* 2017). *H. erinaceus* can be sourced from cultivated specimens or wild-collected specimens, often depending on the region. It is heavily collected in America and East Asia, and it is cultivated with relative ease (Kalucka & Olariaga Ibarguren, 2019). There appears to be a lack of data upon the import and export of *H. erinaceus*, although the IUCN suggests that trade is national, but not international.

Hydnum

Figure 24: *Hydnum spp.* showing the characteristic tooth-like projections on the underside (Digifolia, 2024).

Genus Characteristics

Hydnum spp., commonly known as Hedgehog fungus, is a genus of approximately fifty edible ectomycorrhizal fungi (Feng *et al.,* 2016; Niskanen *et al*., 2018). They are globally distributed in woodlands (Sugawara *et al.,* 2021), with commonly harvested species *H. repandum* and *H. rufescens* being found across multiple continents (Sugawara *et al.,* 2022). Their defining characteristic is the white, brittle tooth-like projections on their undersides (Fig. 24) from which spores drop, as opposed to more commonly seen gills (Antonyuk *et al*., 2020).

Threats

H. repandum is the only *Hyndum* species listed on the IUCN and on the Global Fungal Red List Initiative. It has been listed as Least Concern, and as having a stable population. Their wide distribution and lack of host specificity makes them less vulnerable to environmental change than other species (Feng *et al.,* 2016). However, experts note the species in *Hydnum* are extremely hard to tell apart with the naked eye, even by specialists and further research is required to determine the threats to the species in this genus.

Utilisation and trade

There is little information regarding the international trade in *Hydnum* species. Nevertheless, *H. repandum* is suggested to be an internationally highly appreciated edible mushroom that is collected and sold in local markets of Europe (IUCN, 2024; Harrington & Cullen, 2008). It and its relatives, *H. albidum,* *H. albomagnum,* and *H. rufescens,* are suggested to be gourmet edible fungi. For instance, the wholesale price of fresh hedgehog mushrooms was $13.3 per kg in Barcelona, Spain, in 2002, and both *H. repandum* and *H. umbilicatum* are consumed in the United States in late spring (Sugawara *et al*., 2019). *H. repandum* is suggested to be one of the most important internationally marketed wild edible mushrooms harvested from the Pacific Northwest (Pilz & Molina, 2002;). Despite this economic importance, reliable pure cultures have not been established (Sugawara *et al*., 2019). It may also be accidentally harvested as a look-alike species for members of the genera *Cantharellus* and *Craterellus* (Antonyuk *et al*., 2020).

Inonotus

Figure 25: *Inonotus obliquus* with the clearly visible contrast black external surface and orange-brown internal surface (Shutterstock, 2022).

Genus Characteristics

Inonotus spp. is a parasitic genus of approximately eighty species, may be characterized by the presence of fibrous and compact masses of mycelium (Fig. 25) on the surfaces of trees, called sclerotium. Much like *Fomes spp.* They cause white rot diseases in both broad-leaved and coniferous trees (Lee *et al.,* 2008; Leonardo-Silva *et al*., 2021). *Inonotus spp.* are globally distributed, but with a larger number found in the Northern Hemisphere (Fordjour *et al.,* 2023; Lee *et al.,* 2008; Leonardo-Silva *et al*., 2021).

Threats

It is currently unclear whether *Inonotus* species are under threat from international trade, however species may be threatened in the future with an increasing demand and a lack of cultivation. There are no members of the genus *Inonotus* listed upon the IUCN, however there are four listed upon the Global Fungal Red List. Here, the highly traded *I. obliquus,* commonly known as chaga, is assessed to have been Least Concern, but this is yet to have been published. While it is widely distributed, overharvesting can be local and form a regional threat. Moreover, poaching on private lands may be a problem within the USA. Generally, however, the species is common and widespread in Eurasia, with no evidence of decline (IUCN, 2024). Nevertheless, there has been a lack of research into the impact of commercial harvesting upon *I. obliquus* populations.

This is concerning, because there is a rising interest in chaga products (Pilz, 2004). Sterile conks are harvested before they have produced spores, which they do towards the end of their lifespan. The impact of this pre-sporulation phase harvesting is currently unknown, however chaga can regrow to harvestable size again in three to ten years

(Thomas *et al.,* 2020). Still, this lack of knowledge combined with the fact that *I. obliquus* takes many decades to form reproductive structures could put the species at risk from increased exploitation (Thomas *et al.,* 2020; Pilz, 2004). *I. obliquus* is also threatened by commercial foragers and loggers (IUCN, 2024). More information is needed to be able to inform legislation regarding *I. obliquus*. While methods and regulations for commercial harvesting are well developed within Russia, the methods for ascertaining the size or extent of the resource, and to what degree increased commercial harvesting for export markets might be sustainable, are currently underdeveloped (Pilz, 2004).

<u>Utilisation and trade</u>

I. obliquus is the most internationally traded *Inonotus* species, and it appears to be commercially valuable for its pharmaceutical properties. It is currently being investigated for immunological-enhancing and anti-carcinogenic activity, leading to an expansion in world markets (Pilz, 2004). Furthermore, liquid extracts of *I. obliquus* are commercially available for pharmaceutical use, as are dried and powdered sterile conk, oral capsules, tea, and a wide range of other products (Lee *et al.,* 2008; Thomas *et al.,* 2020). These products are typically presented as being beneficial to health (Thomas *et al.,* 2020).

The international trade in *I. obliquus* appears to be increasing. It has traditionally been used in Russia and Finland, who now export it internationally. *I. obliquus* has also been sold elsewhere in Europe, however the North American market is largely undeveloped (Pilz, 2004). A search for 'Chaga health products' returned 1,390,000 results on Google.com in 2019, and over 4,000 products with the keyword 'Chaga' could be found on Amazon.com (Thomas *et al.,* 2020). It has recently gained demand in Asia, particularly Japan and South Korea. Here, buyers prefer to purchase *I. obliquus* in bulk, before processing it into final products within their own countries (Pilz, 2004). There does not appear to be a comprehensive database of the economic value of *I. obliquus* import and export. Generally, information upon *I. obliquus* harvesting is also scarce within the literature, and especially within the English literature (Pilz, 2004).

I. obliquus products are currently sourced from wild populations. While attempts have been made to culture *I. obliquus,* with the intention of better fueling increasing demands for it, the compounds found in the artificially propagated chaga did not match those which were found in the wild chaga (Miina *et al.,* 2021; Thomas *et al.,* 2020). Studies appear to be continuing to investigate the artificial propagation of *I. obliquus*, and at least one study has demonstrated the potential for large-scale commercial cultivation within set-aside birch stand (Miina *et al.,* 2021).

Lactarius

Figure 26: A cluster of *Lactarius indigo* in a bed of grass and leaf litter (Digifolia, 2024).

Genus Characteristics

Lactarius commonly known as milkcaps, is a genus of edible ectomycorrhizal fungi (Rinaldi *et al*., 2008). Identifiable by their brittle flesh and milky latex exudate when damaged (Courtecuisse & Duhem, 2013), they are commonly found in temperate forests (Courtecuisse & Duhem, 2013). They exhibit a range of host specificities, with some species able to colonise both broadleaved and coniferous trees (Courtecuisse & Duhem, 2013; Verbeken & Buyck, 2002), whereas others such as *L. lilacinus* only colonise tree in the genus *Alnus* (Rochet *et al*., 2011). They are globally distributed, but more commonly found in the Northern hemisphere (Courtecuisse & Duhem, 2013; Geml *et al*., 2009) and many species have been introduced beyond their natural range in association with movement of their preferred host trees (Vellinga *et al.,* 2009).

Threats

There is insufficient evidence to suggest that *Lactarius spp.* are at risk from international trade. There are thirty-eight *Lactarius spp.* listed on the IUCN. Of these, four are Endangered (*L. acatlanensis, L. coccolobae, L. fuscomarginatus, L. novae-zelandiae*)*,* two are Vulnerable (*L. haugiae, L. strigosipes*)*,* one is Near Threatened (*L. mediterraneensis*) with the rest being least concern, data deficient or at the proposal stage (IUCN, 2024). A review of officially or unofficially published global, national, and regional Red Lists found that thirty-seven species of milkcaps were listed as Critically Endangered, and forty-one were listed as Endangered (Leonardi *et al.*, 2021). *L. deliciosus*, the seemingly most economically important species of *Lactarius*, is absent from the IUCN. It is also absent from the Global Fungal Red List Initiative. However, *L. rubidus*, another species that appears to be traded internationally, is designated as Least Concern upon both the IUCN and the Global Fungal Red List Initiative. It is suggested to have no global threats, and it has been noted that no decline in abundance due to over harvesting has been observed. Furthermore, there is little information in the literature to suggest that *Lactarius spp.* are currently at risk from international trade, although they may benefit from harvesting-free protected areas. This would alleviate damage from trampling (Leonardi *et al.*, 2021; Román & Boa, 2006).

Utilisation and trade

Lactarius spp. are among the most consumed and traded species of wild edible fungi (Willis, 2018). This has made them into some of the most valuable mushrooms in Europe. *L. deliciosus* is particularly valuable, (Guerin-Laguette *et al.,* 2014; Mumcu Kucuker & Baskent, 2019; Román & Boa, 2006). *L. salmonicolor, L. rubidus, L. semisangifluus*, and *L. vinosus* also appear to be traded nationally, and perhaps internationally (Guerin-Laguette *et al.,* 2014; Mumcu Kucuker & Baskent, 2019; Román & Boa, 2006). *Lactarius spp.* are traded commercially for their use as food. *L. rubidus*, for instance, is a highly prized edible for use in desserts, with dried specimens selling for approximately $715 per kg (IUCN, 2022).

Despite their apparent national trade, little to no information appears to be available in the literature or trade databases with regards to the import and export of *Lactarius*. It is therefore unclear whether trade is mainly national, or whether it has a significant international component. Nevertheless, the demand for *L. deliciosus* (Fig. 27) is increasing within certain regions of Spain, where it one of the main wild edible fungi exports. The trade in *L. sanguifluus* and *L. semisangifluus* is likely also increasing, as they are traded alongside *L. deliciosus* under the shared name of 'Saffron milk cap' (Román & Boa, 2006). While the level of international trade in *L. deliciosus* is unclear, in some regions it seems to be primarily traded locally (Román & Boa, 2006; (Adanacıoğlu *et al.,* 2017).

Figure 27: *Lacterius deliciosus*- the most commonly trade species in this genera (Shutterstock, 2022).

Currently, *Lactarius spp.* appear to be primarily wild collected. The collection of *Lactarius spp.* provides a good source of income to local collectors in Spain, where collectors carefully cut the stalks of the mushrooms at the base and allow a space of two days between harvesting sessions so that the mushrooms can grow (Román & Boa, 2006). The cultivation of *Lactarius spp.* also shows promise for the future. *L. deliciosus* has successfully been cultivated in France and New Zealand, and *L. hatsutake* has successfully been cultivated in China (Guerin-Laguette *et al.,* 2014; Wang & Chen, 2014). Moreover, the planting of *Pinus nigra* in Spain has assisted in the development of commercial markets for *L. deliciosus* over the last 30 years (Boa, 2004). *L. deliciosus* has been introduced with *Pinus* hosts in large areas outside its original range, and it is one of the few ectomycorrhizal mushrooms to have been successfully cultivated (Leonardi *et al.*, 2021).

Lichens

Figure 28: Mixed lichen genera on stone, including *Caloplaca sp.* (orange), *Lecanora sp.* (green) and *Candelariella sp.* (yellow). This demonstrates the morphological diversity of this group (Mullins, 2024).

Group Characteristics

Lichens (Fig. 28) are a diverse group of between thirteen- to twenty-thousand organisms (Daniel & Polanin, 2013; Lücking *et al*., 2017). They are a complex symbiosis of three partners: single-celled algae or cyanobacteria, fungi (of which there may be more than one species) and a yeast (Brodo & Duran Sharnoff, 2001; Lepp, 2011; Spribille *et al*., 2016). The algae or cyanobacterial partners are eukaryotic, photosynthetic organisms that supply energy to the organism (Lepp, 2011; Sarmah, 2022). These are surrounded by three layers of fungal filaments; the densely packed, protective cortex on the surface, the loosely packed photobiontic layer that allows for air circulation and the root-like medulla that anchors the lichen to its substrate (Brodo & Duran Sharnoff, 2001). The yeast partner is embedded in the cortex (Velmala *et al*., 2009) and is theorised to supply antimicrobial and anti-grazing compounds (Spribille *et al*., 2016; Velmala *et al*., 2009) to protect the lichen (Fig. 29).

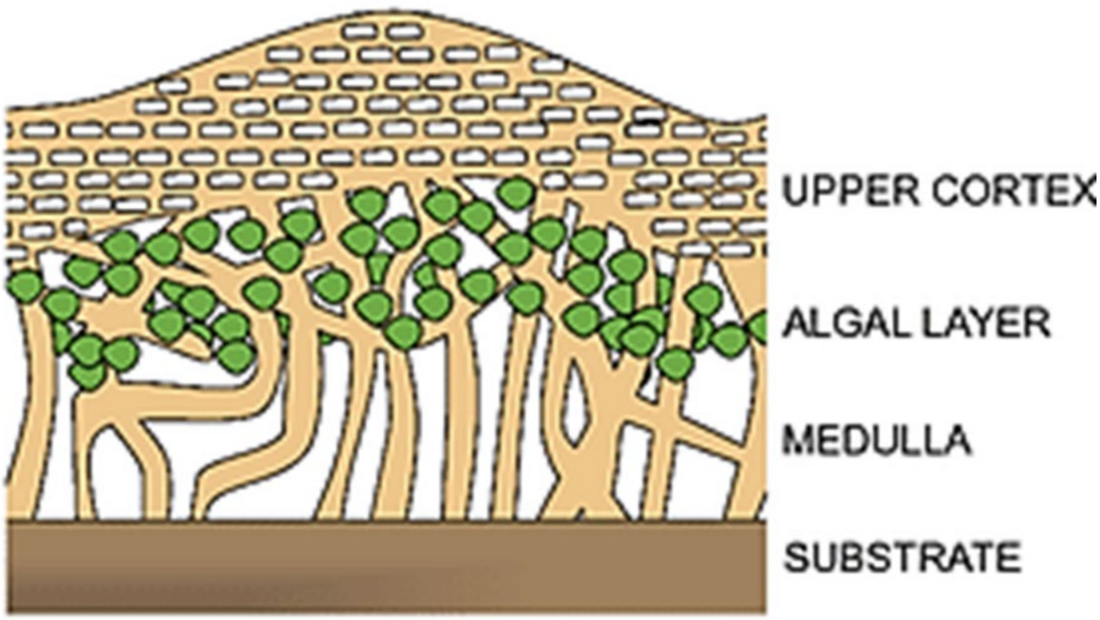

Figure 29: Anatomy of a simple lichen structure, showing the fungal hyphae layers (Adapted from Reinoso *et al.,* 2021).

Fungi are classified according to the species of the fungal partner (or mycobiont), and it is worth noting that one fungus may form lichens with different algae, but that these are still classed as the same lichen species (Kirk & Cannon, 2008). It has been proposed that 20% of all fungal species may be lichenised (Ramel, 2015).

Lichens have many forms and no obvious characteristics in terms of their gross anatomy that are common to all (Lepp, 2011). The main body, or thallus, can be categorised according to the type of overall structure, and this is usually determined by the fungal partner – also called the mycobiont (Lepp, 2011). For example, foliose lichens have flat, leaf-like thalli, whereas fruticose lichens have rounded, moss-like thalli (Dobson, 2011; Sharnoff & Sharnoff, 2015). They can also be highly pigmented (Sharnoff & Sharnoff, 2015), which is determined by the photosynthetic partner and the presence of specialised secondary metabolites, such as Usnic or Vulpinic Acid (Jones Medlin & Jain, 1996).

Lichens are globally distributed, colonising some of the most inhospitable regions of Earth, including bare rock faces, tundra and toxic waste (Klein, 2019; Lepp, 2011; Speer & Waggoner, 1997). Some species have become adapted to environmental niches that few plant species have colonised, such as saline environments or permafrost (Lepp, 2001; Oksanen, 2006). In the UK, they are typically seen on tree bark in temperate woodlands, walls, masonry and bare soil (Lepp, 2011; Sharnoff & Sharnoff, 2014).

Threats

The IUCN Global Fungal Red List contains four hundred and seven lichens, of which twenty-four are Critically Endangered, thirty-six are Endangered and twenty-seven are Vulnerable (IUCN, 2024). The most used species in the UK, *Parmelia saxatilis* (Fig. 30), is listed as Least Concern, due to its abundance in the Northern Hemisphere (Yahr, *et al.,* 2021). Another internationally traded UK species, *Cetraria islandica,* is in the proposal stage of red-listing, but is listed on Annex D of the EU Wildlife Trade Regulations. It is reported to abundant from the north of Scotland, Scandinavia and Canada up to the Artic Circle (Matthews, 1993), as well as Alpine regions of Mid- to Eastern Europe (European Medicines Agency, 2014). The populations are likely to be in decline due to the changing climate (Sinigla *et al*., 2015) and it is particularly vulnerable to the effects of pollution and acid rain (Sánchez *et al.*, 2022; Sinigla *et al.*, 2015). Nepal and North India report significant trade in species that are used as dyes (Devkota *et al.*, 2020), including *Hypotrachyna cirrhata, Hypotrachyna nepalensis* and *Parmotrema cetratum.* None of these are included on the Global Fungal Red List, despite collection and trade in lichens for commercial purposes being banned in Nepal since 2011 (Devkota *et al.,* 2020). Another species, *Umbilicaria esculenta*, is available to buy internationally, and is also missing from the Red List, but has been categorised as endangered by in China (Wei *et al.*, 2022) and in the Primorye territory of the Russian Federation (Skirina, 2020).

Figure 30: *Parmelia saxatillis* (Digifolia, 2024).

Due to the requirement for specific symbiotic partners and niche adaptations, some lichens can only be found in very specialised habitats (Giordani *et al.*, 2020), making them vulnerable to even slight changes in the environment. This includes the effects of climate change, as the algae partners are less able to adapt to increasing global temperatures than the fungal partner, risking the survival of the species (Nelsen *et al.*, 2022; Wrobleski *et al.*, 2023). The loss of undisturbed habitats and areas of biodiversity also poses significant threats to lichens, especially those adapted to specific ecological niches (Outhwaite *et al.,* 2020).

Illegal harvesting of lichens in Nepal and North India for the international market has been linked to a decline in wild populations (Devkota *et al.,* 2017; Maraseni & Shivakoti, 2003). In Uttarakhand, India, where the trade is regulated but not banned, training in sustainable harvest practices has been demonstrated to have positive effects on the lichen population (Shah, 2014).

<u>Utilisation and trade</u>

Lichens have found many uses throughout history, but few have persisted in international markets today. Many lichen species are edible and are an important part of indigenous diets across the world (Zhao *et al.*, 2021), but generally edible lichens are gathered for personal use or for sale on domestic markets (Yang *et al.*, 2021). An exception to this is *Umbilicaria esculenta* (Fig. 31), found at high altitudes across East Asia and considered a delicacy in Japan and Korea (Zhao *et al.*, 2021). This is available to buy internationally online and commands a high price due to its rarity and difficulty of harvesting from high altitudes (Sun *et al.*, 2018). There is no known artificial cultivation of this species. It is difficult to find data on trade volumes of the species, but its reliance on being wild harvested would make it at risk from international trade.

Figure 31: *Umbilicaria esculenta* (Shutterstock, 2024).

Lichens have also been used in the dyeing industry (Fig. 32). Highly pigmented lichens, such as *Roccella tinctoria* and *Parmelia saxatilis* have been used as dyes for scientific and commercial purposes (Perkins. 1986; Rather *et al.*, 2021; Shukla & Upreti, 2015) but have been largely superseded by synthetic versions of their pigments (Rather *et al.*, 2021). Lichens that produce pigments suitable for dyeing are frequently slow-growing and unsuitable for commercial cultivation (Perkins, 1986; Shukla & Upreti, 2015), so artisanal industries that use lichen dyes typically use wild-harvested specimens. However, there is limited evidence that lichens are internationally traded for this purpose.

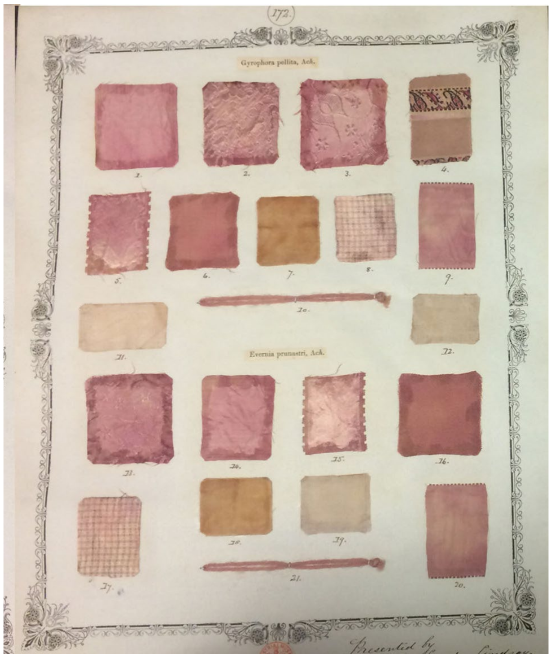

Figure 32: A range of historic swatches of Lichen based dyes from *Umbillicaria polyrrhiza* and *Evernia prunastri* (Royal Botanic Gardens, Edinburgh, 2018).

The main international trade in lichens is in traditional medicine, often as topical pesticides (Upreti *et al*., 2005). There is evidence of international trade of wild-harvested genera *Lethariella*, *Parmeliaceae* and *Physiaceae* from Nepal to India, and from Nepal and India to China for the medicinal trade (Devkota *et al.,* 2017; Upreti *et al*., 2005; Yang *et al.,* 2021), however trade volumes are not uniformly reported. It was reported that trade volumes in lichens from the Uttarakhand region of India between 1999-2011 peaked at 567,075 kg, with the annual average international trade volume being 168,350 kg (Devkota *et al.,* 2017). However, this does not cover the full breadth of species being traded in the region and thus it cannot be stated with certainty that wild harvest is not detrimental to species survival. *Cetraria islandica* is also used medicinally in Europe, as a laxative and expectorant (Richardson, 1988, Sànchez *et al*., 2022), as well as being edible (Porsild, 1954). Dried products and extracts are readily available online, typically originating from Eastern Europe (European Medicines Agency, 2014). There are no reports or records of artificial propagation of *C. islandica* (IUCN, 2024), and with the likelihood of decreasing populations there is the risk that harvesting for the international market could hasten the decline.

Morchella

Figure 33. Artificially propagated *Morchella sp.* in Copenhagen, Denmark (The Danish Morel Project, 2021).

Genus Characteristics

Morchella is a distinctive genus, commonly known as Morels (Fig. 32). They are characterised by their convoluted network of ridges on their caps, giving them a honeycomb appearance (Loizides, 2017). Whilst they are globally distributed as a genus. They are mostly found in temperate zones of the Northern Hemisphere (Kuo *et al*., 2012), and individual species are generally endemic to small geographic regions (O'Donnell *et al*., 2011). Although not ectomycorrhizal in the true sense (Dahlstrom *et al.,* 2000; Tedersoo *et al*., 2010), many species are associated with trees, with some species theorized to be symbiotic (Tedersoo *et al.,* 2010) and others parasitic (Dahlstrom *et al*., 2000). Unusually for fungus, they are pyrophiles that grow abundantly after forest fires, due to the increased alkalinity of the soil (Greene *et al*., 2010).

Threats

The level of threat posed by international trade towards *Morchella spp.* does not appear to have been rigorously evaluated. There are currently no species of *Morchella* listed on the IUCN. However, given their widespread collection for human use, research and monitoring to support their sustainable management and conservation seems necessary (Larson *et al.,* 2016). High harvest levels in the Pacific Northwest and prolonged harvest pressure in Europe have raised some sustainability concerns, although declines in European mushrooms are often due to land conversion, soil compaction, and climate (Malone *et al.,* 2022). *Morchella spp.* are also traded by Nepal, although concerns of over exploitation are being raised in some areas, this trade does not appear to be having a serious impact. Nevertheless, due to high market demand, the unsustainable collection of *Morchella spp.* is increasing (Raut *et al.,* 2019).

<u>Utilisation and trade</u>

Morels are commercially important edible mushrooms that may have economic significance upon the world market. However there does not appear to be a unifying database upon their international trade data (Pilz, 2004; Larson *et al.,* 2016; Raut *et al.,* 2019; Barron & Emery, 2009). Wild morels are harvested commercially for export from China, India, Pakistan, Turkey, Mexico, and the United States. In China, the annual export of dried morels has increased five times from 181 to 900 tons over the past few years (Raut *et al.,* 2019). Moreover, the U.S. Forest Service records show that approximately 350,000 kg of morels were harvested each year from national forests in Oregon and Washington in 2004 and 2005 (Barron & Emery, 2009). There is no exact figure available for the collection and export of morels from Nepal, but it is estimated that 1.7 to 6.5 tons of dried morels are exported annually. These morels are typically exported to Europe, especially France, Switzerland, Germany, Belgium, and the Netherlands (Raut *et al.,* 2019). It has been suggested that, in 1993, the international commerce in morels was worth approximately $15-18 million (Barron & Emery, 2009).

Figure 33. *Morchella importuna* (Shutterstock, 2024).

Some morels can be cultivated (Fig. 32), while others are wild collected. It has been suggested that currently only black and red morel clades can be cultivated, while yellow clades cannot (Xu *et al.,* 2022). Most Morels on the international market will have been wild harvested, due to the difficulties in cultivation and seasonal growth (Pilz *et al.,* 2007). Black morels (Fig. 33) are of high economic value, and several species have recently been domesticated in China for use in large-scale outdoor mushroom crop production. The black morel agroindustry is now expanding rapidly In China and around the world (Zhang *et al.,* 2023). Domesticated species of black morel in China include *M. importuna*, *M. sextelata*, *M. eximia, M. exuberans, and M*. owneri (Raut *et al.,* 2019; Willis, 2018; Xu *et al.,* 2022; Zhang *et al.,* 2023). In contrast, cultivation and conservation measures have not yet been properly implemented in Nepal, so morels are typically taken from the wild. The most traded morels in Nepal are *M. conica* and *M. esculenta* (Raut *et al.,* 2019). Similarly, with the exception of the US-cultivated *M. rufobrunnea*, morels are generally harvested from the wild in North America. Here, *M. esculenta* and *M. conica* are also the most sought-after morels for commercial export, as are burn morels (Larson *et al.,* 2016; Raut *et al.,* 2019; Rowe, 1997; Xu *et al.,* 2022).

Ophiocordyceps

Figure 34. Harvested *Ophiocordyceps sinensis* showing the mummified caterpillars to the right of the organism and the stiff, fungal fruiting body on the left (Dema, 2021).

Genus Characteristics

Ophiocordyceps is a genus of approximately one hundred and forty species of parasitic fungi that grow on insect hosts (Kirk *et al.,* 2008). Like *Cordyceps,* they lethally parasitize arthropods, but differ in their tough, pliable bodies – or stromata – as opposed to the fleshy stromata of *Cordyceps* (Lo *et al.,* 2013). They are genetically distinct enough to have been reclassified from *Cordyceps* by Sung *et al.,* (2007) based on phylogenetic analysis of multiple gene loci. However, this can present nomenclature confusion, as *Ophiocordyceps sinensis*, the Caterpillar fungus, is frequently referred to by its synonym *Cordyceps sinensis*.

O. sinensis, the most popularly traded *Ophiocordyceps* species, parasitises the larvae of *Hepialidae* moths in the Himalayas and Tibetan plateau (Zhu *et al*., 1998). It mummifies the larvae after germinating inside it, emerging as a stiff fruiting body from the head (Xing & Guo, 2008). Both the fruiting body and host corpse are considered valuable in traditional medicine (Halpern, 2002).

Threats

The main *Ophiocordyceps* species in trade is *O. sinensis*, which has gained international attention for its potential overexploitation by international trade. It is listed as Vulnerable on the IUCN, and it has been listed as a threatened species under the second category of state protection in China since 1999 (Xiao-Liang & Yi-Jian, 2011). The major threat to the species is its unregulated, large scale, and increasing harvest from throughout its range. In addition to over-collection by humans, it is also threatened by over-grazing, under-grazing, harvesting of trees for firewood, other changes in vegetation cover, nitrogen pollution, and climate change (Nxumalo *et al.,* 2020; TRAFFIC, 2023; Yang, 2020). Because the species has a strict host-specificity and a confined geographic distribution, its natural production is very limited. This suggests that, particularly when considering its other threats, the species will be unable to supply the increasing demands (Sharma, 2003; Zhang *et al.,* 2020). Moreover, this high demand may also result in destructive harvesting practices. It has been suggested that gatherers extract *O. sinensis* using destructive methods, without considering sustainability. Their main aim is to achieve maximum harvest for income generation, which is dependent on how many specimens they obtain. The result is a further reduced resource availability (Sharma, 2003). With sufficient regulation mechanisms, incentives for sustainable harvest could be made. However, currently these are not in place (TRAFFIC, 2023).

Utilisation and trade

O. sinensis is a highly valuable traditional Chinese medicine and has been used as a treatment for cancer, asthma, inflammatory diseases, for ailments of the lungs, kidney, and liver, and as an aphrodisiac (Lu *et al.,* 2019; Nxumalo *et al.,* 2020; TRAFFIC, 2023; Willis, 2018; Yang, 2023;). Recent research has shown a variety of beneficial effects in animal testing, such as increased physical endurance (Yang, 2020). Generally, *O. sinensis* is consumed in its raw state, but it is sometimes processed into a powder (Zhang *et al.,* 2020).

O. sinensis (Fig. 34) is one of the world's most expensive natural medical resources, and there is both an increasing price and an increasing demand (TRAFFIC, 2023). It is especially valuable in China. For example, one kg of the fungus was sold here at $700. Moreover, it is believed that in the international market the fungus may be priced between $20,000 to $40,000. The collection of *O. sinensis* to fuel this export has become the most important source of income in rural Tibet (Willis, 2018). Seasonal collection of the fungus is a rare avenue of income-generation in the interior regions of mountains, where livelihood options are limited (Sharma, 2003). In Tibet, the trade in the species contributes more than 40% of annual cash income to local households, and to almost 10% of the Gross Domestic Produce (GDP) (Yang, 2020).

Much of the trade in *O. sinensis* is hidden, and some of it is likely to be illegal; this makes it more challenging to garner international trade data for the species. Illegal trade networks begin in high-altitude villages in India, before travelling through the porous Indo-Nepal border via several informal trade channels (TRAFFIC, 2023). By collecting material from different sites, the brokers and agents obtain a higher price, however the gatherers do not typically see the benefit of this (Sharma, 2003). From Nepal, they are then exported to international traditional medicine markets (TRAFFIC, 2023). The high price of the fungus and its vulnerability to theft and loot make the transaction secretive, and the rest of the trade is under-surface due to its cross-border nature (Sharma, 2003).

While attempts have been made to cultivate *O. sinensis* to meet demands, it is a difficult process and has so far been commercially limited. A Chinese strain is culturable in artificial medium, and the products have been made commercially available in the USA and Canada (Nxumalo *et al.,* 2020; Sharma, 2003). However, in general, the species does not see commercial cultivation (Yang, 2020). This is despite the promising medicinal properties of products in experimental and clinical trials (Sharma, 2003), as well as a marked increase in products using it, with an average of forty-six patents filed per month in 2019-2020 (Hinsley *et al.,* 2024). Indeed, *O. sinsensis* has been flagged as a priority species for conservation action because of this significant increase in patents, as patent filing is a predictor of international trade (Hinsley *et al.,* 2024). Therefore, wild *O. sinensis* populations are heavily exploited and at risk from international trade.

Tricholoma

Figure 35: *Tricholoma magnivelare* bearing remarkable similarity to *Agaricus bisporus* (Trudell, 2012).

Genus Characteristics

Tricholoma is a large genus of three hundred and seventy-nine species of (mostly) edible ectomycorrhizal fungi (Watkinson, 2016). They grow in association with broad-leaved and coniferous trees in Northern Hemisphere forests (Guo et al., 2016) and have broad host ranges (Guo et al., 2017; Watkinson, 2016). *Tricholoma* is a morphologically varied genus, with the only common trait being the presence of white spores, a characteristic shared with other genera (Trudell, 2012).

Threats

Tricholoma spp. may be threatened by destructive harvesting practices and overexploitation as a result of international trade. There are four *Tricholoma spp.* listed on the IUCN, and all of these are Vulnerable (IUCN, 2022). *T. matsutake* is threatened by harvesting in Russia, and populations in Japan and other intensively harvested areas may have declined due to collection techniques such as the removal of soil and leaf litter by raking (Brandrud, 2020). Raking can occur when a harvester is new to a mushroom patch, or when harvesters are attempting to find younger specimens. These specimens are significantly more valuable because they arrive at Japanese markets in better condition. However, they have not yet spread their spores. The intense competition between harvesters increases the chance that, even if one harvester leaves the mushroom to mature, another harvester will simply collect it. Raking has also been shown to have a long-term negative impact on *T. magnivelare* (Fig. 35). It seems plausible that digging the forest floor might damage the mycelium and reduce fruiting (Amend *et al.,* 2010; Brandrud, 2020; Pilz & Molina, 2002; Pilz *et al.,* 1999).

Tricholoma matsutake (Fig. 36) is heavily exported from China, and it is one of only two species to have been listed as a threatened species under the second category of state protection in China since 1999 (Willis, 2018). It has also been placed on China's CITES Category II protected list, and requires permits for export (Amend *et al.,* 2010). In some areas, harvesting mushrooms less than 5 cm is subject to a fine, and most areas regulate against destructive harvesting habits such as removing leaf litter to detect emerging buttons or excessive excavation to ensure harvest of entire stipe. (Amend *et al.,* 2010).
Tricholoma spp. populations are also under a number of other pressures, meaning that sustainable harvesting is important. In the last century, there has been a huge decline in the number of matsutake fruiting bodies in Japan. Productivity has declined to less than 10% of its pre-1937 levels (Amend *et al.,* 2010; Hosford *et al.,* 1997; Matsutake Worlds, 2009).

Figure 36: *Tricholoma matsutake* (Shutterstock, 2022).

An introduced pathogen and a change in forest demographics following adoption of natural gas stoves have resulted in loss of *T. matsutake* habitat. *T. matsutake* is also threatened in Europe due to habitat loss, and in Russia due to clearcutting and degradation of habitats (Amend *et al.,* 2010; Brandrud, 2020). The growth of wild *T. matsutake* is slow and limited to strict environmental conditions, including a lack of pollution. Furthermore, the amount of suitable habitat for *T. matsutake* is predicted to decrease with climate change. Because artificial cultivation is currently unavailable, wild populations may be at risk from the added pressure of unregulated harvesting (Guo *et al.,* 2017).

Utilisation and Trade

T. matsutake and related species are highly valuable, edible fungi, and they are sold in both international and local markets (Brandrud, 2020; Luoma *et al.,* 2006; Pilz *et al.,* 1999; Román & Boa, 2006; Sitta & Davoli, 2012; Wang & Chen, 2014). The species of Tricholoma in trade are *T. matsutake*, *T. magnivelare*, *T. caligatum*, and *T. anatolicum* (Yun *et al.,* 1997; UN Statistics Division, 2024). *T. matsutake* is primarily traded between Asian countries, particularly via its export from China and South Korea to Japan (Boa, 2004; de Frutos, 2020; Yun & Hall, 2004). Overall, Japan dominates the import market for matsutake (Tab. 7). This is because matsutake are the most appreciated edible mycorrhizal fungi in Japan, and because Japanese matsutake populations cannot supply this demand (Saito & Mitsumata, 2008; Wang & Chen, 2014).

The export of *T. matsutake* in South Korea and China generates $20-80 million/year to rural populations, and China alone has exported more than 500-600 tons of matsutake per year to Japan since the 1990s. This has provided a significant source of income to poor, remote, mountainous communities (Yun & Hall, 2004). Japan also imports *T. magnivelare* from Canada, the USA, and Mexico, at quantities of 500-700 tons per year (Tab. 8). This again provides a locally important source of income, and there is a multi-million-dollar matsutake industry in the Pacific Northwest region of North America (Yun & Hall, 2004; Luoma *et al.,* 2006; Amaranthus, 2000; León et al., 2002; Miriam de Román & Boa, 2006; Pilz *et al.,* 1999).

Table 8: The ten largest exporters of *Tricholoma spp.* in 2022, according to UN Comtrade database. Belgium and France also had less economically significant levels of export.

Rank	Country	Trade Value (US$)	Net Weight (kg)
1	China	13,310,897	168,790
2	Italy	1,526,647	622,345
3	USA	387,812	17,750
4	Romania	385,391	48,586
5	Rep. Of Korea	259,224	3831
6	Türkiye	152,256	7176
7	Bulgaria	148,763	5416
8	Netherlands	43,518	7523
9	Canada	33,892	1482
10	Japan	25,004	117

Table 9: The ten largest importers of *Tricholoma spp.* in 2022, according to UN Comtrade database. Other countries, such as the Netherlands, Romania, Singapore, the USA, and Switzerland also had less economically significant levels of import.

Rank	Country	Trade Value (US$)	Net Weight (kg)
1	Japan	30,781,468	407,694
2	Italy	16,730,262	3,220,128
3	Rep. Of Korea	1,625,350	67,714
4	Belgium	439,168	83,055
5	Canada	389,858	17,865
6	France	326,615	122,631
7	Portugal	206,888	90,743
8	Germany	183,799	49,704
9	Spain	102,294	26,333
10	China, Hong Kong SAR	77,587	N/A

Matsutake specimens in trade are of wild origin (Brandrud, 2020). *T. matsutake* cultivation is a significant area of research in Japan and Korea, but no success has been reported. This means that harvested matsutake is of wild origin (Wang & Chen, 2014), which may prove detrimental to the species survival at the levels seen in international trade.

Tuber

Figure 37: Cross section and outer surface of the highly sought after Black Truffle, *Tuber melanosporum* (Chauhan *et al.,* 2021).

Genus Characteristics

Tuber is a genus of approximately one hundred and eighty ectomycorrhizal fungi, that exclusively grow underground (Mishra *et al*., 2023; Obase *et al*., 2021). Commonly known as truffles, they are found predominantly in the Northern Hemisphere, in association with *Pinaceae, Fagaceae, Myrtaceae,* and *Salicaceae* host trees (Bonito & Smith, 2016). The genus is characterised by potato-like fruiting bodies and production of volatile organic compounds that allow for animals to detect and disperse their spores (Obase *et al.,* 2021). It is these aromatic compounds that contribute to their unique flavour and thus high market value.

Threats

There are no members of the *Tuber* genus on the IUCN, although four species are listed on the Global Fungal Red List Initiative (IUCN, 2024). Of these, two may be threatened by overexploitation. *T. indicum* is at threat from the over collection of mature fruit-bodies, and the collection of young-fruit bodies that have not yet sexually reproduced. This has led to its preliminary assessment as Near Threatened. Similarly, *T. castellanoi*, is a member of the *Tuber gibbosum* complex, making it a highly sought-after commercially traded species. Harvest by indiscriminately raking the duff and topsoil to expose the truffles is detrimental to the habitat and long-term viability of the species. It is currently under assessment (IUCN, 2024).

There is evidence of overexploitation and unsustainable harvesting practices of truffles.

For instance, Spanish wild truffle production suffered a sharp decline during the 1970s and 1980s. This is suggested to be due to a lack of regulation, resulting in extreme competitiveness among harvesters, poaching, overexploitation, excessive trampling, and damaging picking techniques (Garcia-Barreda *et al.,* 2018). This has similarly been found to have been the case for *T. indicum* in China. This species was also intensely harvested for commercial purposes and, as its price sharply increased, damaging picking techniques became widely employed. This has resulted in a 30-50% decrease in harvests after about 30 years of unregulated use (Garcia-Barreda *et al.,* 2018). Moreover, the indiscriminate collection of *T. magnatum* has also been found to result in insufficient annual production to meet demands (Monaco *et al.,* 2022).

Unsustainable harvesting practices include moving woody debris on the forest floor and raking forest litter layers to search for young mushrooms. This often occurs under intense competition, or when harvesters search for new mushroom patches in areas that they have not previously visited. Raking harms truffle populations by disturbing mycelium or disrupting sporocarp formation (Pilz & Molina, 2002). While some truffles are cultivated, the majority are wild-sourced due to host specificity and the requirement for specific bacterial symbionts in the soil, that are difficult to artificially replicate (Mishra *et al.,* 2023).

In addition to harvesting, truffle populations face other pressures, such as the effects of climate change. Increased likelihood of drought in Mediterranean areas has been proposed as likely to decrease species abundance (Čejka *et al.,* 2022; Rosa-Gruszecka *et al*., 2017) and warmer climates could increase the range of pest insect species, such as *Leiodes cinnamomea,* that lay eggs in the fruiting bodies, causing extensive damage (Rosa-Gruszecka *et al.,* 2017).

Figure 38: *Tuber magnatum*, the White Truffle (Shutterstock, 2022).

Trade and utilization

Tuber spp. form truffles, which are some of the most expensive edible mushrooms in the world. The most economically important species are *T. melanosporum* (Fig. 37), *T. aestivum*, *T. magnatum* (Fig. 38), and *T. indicum*, although other species may also be economically important (Čejka *et al.,* 2020; Garcia-Barreda *et al.,* 2018; Monaco *et al.,* 2022; Wang & Chen, 2014; Willis, 2018). *T. uncinatum*, *T. macrosporum*, *T. mesentericum*, *T. borchii*, and *T. brumale*, for instance, are suggested to be traded internationally on European markets (Tab. 9). Furthermore, *T. gibbosum* and *T. oregonense* are suggested to have been traded on North American markets (Wang & Chen, 2014). According to the UN Comtrade database, Italy, Spain, and Eastern Europe appear to the biggest exporters of *Tuber spp.* (Tab. 10).

Table 10: IMPORTS in 2022. The Republic of Korea, Canada, Denmark, Singapore, Romania, Austria, and the USA also imported *Tuber spp.* in the millions of dollars. Sweden, Belgium, Luxembourg, China, Macao SAR, Norway, Hungary, Portugal, the Netherlands, Australia, Greece, Israel, and Qatar imported *Tuber spp.* in the hundreds of thousands of dollars, and further countries imported *Tuber spp.* in less economically significant quantities.

Rank	Country	Trade Value (US$)	Net Weight (kg)
1	Italy	77,173,709	593,979
2	Japan	15,190,807	20,907
3	France	14,503,779	93,429
4	Switzerland	8,687,785	17,080
5	Spain	7,982,027	80,790
6	Germany	7,573,123	43,423
7	United Kingdom	5,242,279	14,641
8	Croatia	5,085,929	48,945
9	Slovenia	4,167,492	96,215
10	Bulgaria	2,962,544	35,218

Table 11: UN Comtrade - Exports in 2022. Germany, and Hungary also exported Tuber spp. in the billions of dollars. Bosnia Herzegovina, the Netherlands, Belgium, the USA, Belgium, Luxembourg, the UK, Chile, and China, Hong Kong SAR exported Tuber spp. in the hundreds of thousands of dollars, and further countries exported less economically significant quantities of Tuber spp.

Rank	Country	Trade Value (US$)	Net Weight (kg)
1	Italy	65,412,169	275,219
2	Spain	35,612,688	5,119,887
3	Bulgaria	27,268,948	248,070
4	Romania	21,633,081	118,514
5	Croatia	10,525,664	34,321
6	France	9,001,954	43,716
7	Australia	4,919,182	12,075
8	Slovenia	3,081,769	17,761
9	China	1,635,428	20,486
10	Serbia	1,579,607	2829

Some *Tuber spp.* can be cultivated. Cultivation has been attempted since the 1960s. This can either involve sowing oak acorns and relying on the presence of truffle mycelium, or it can involve the inoculation of the roots of young trees with specific mycelia before planting directly into the soil (Bertault *et al.,* 2001). The most cultivated *Tuber spp.* is *T. melanosporum*. It is cultivated in many parts of Europe, such as in Spain, France, and Italy (Čejka *et al.,* 2020; Hall *et al.,* 2003; Stobbe *et al.,* 2013; Wang & Chen, 2014). French "truffle tree" nurseries have a yearly output of approximately 400,000 plants, predominantly inoculated with *T. melanosporum* (Stobbe *et al.,* 2013). Moreover, while the amount, quality, and treatment of inocula, and other details upon other aspects of truffle care are trade secrets, more than half of all *T. melanosporum* truffles are harvested from plantations (Hall *et al.,* 2003). *T. aestivum, T. uncinatum, the T. indicum complex, T. borchii, T. Brumale,* and the desert truffles can also be cultivated, the former being cultivated along its natural distribution (Hall *et al.,* 2003; Wang & Chen, 2014). Out of around 120,000 truffle trees planted each year in Italy, around 15% have been inoculated with *T. aestivum* (Stobbe *et al.,* 2013; Wang & Chen, 2014). Moreover, *T. aestivum* cultivation may be able to extend to new regions as climate change progresses.

Some *Tuber spp.* are yet to be commercially cultivated and are instead harvested from the wild. Some species, such as *T. magnatum,* have resisted most cultivation attempts, and even *T. melanosporum* fields there can be some instability in yield (Stobbe *et al.,* 2013). Furthermore, *T. aestivum* is also still often sourced from the wild (Čejka *et al.,* 2020). In Hungary, natural harvests produce 4-9 tons of *T. aestivum* per year (Stobbe *et al.,* 2013). Italy is the largest truffle harvesting countries, with over 200,000 truffle hunters collecting 90-110 ton per year (Stobbe *et al.,* 2013).

Considerations and Conclusions

This review has identified a variety of fungal genera in trade, both in the UK and internationally, although this is by no means an exhaustive list. As highlighted in the report there is prevalence of wild harvesting and lack of cultivation/artificial propagation for commercially desirable species which may be leading to conservation concerns. For example, *Cantharellus* and *Tuber* genera are commonly wild harvested, and there are documented and anecdotal reports of destructive harvesting practices (such as ground raking) having a deleterious effect on the species (Pilz & Molina, 2002). In such cases, international collaboration, e.g. via CITES, could encourage the implementation of management plans that reduce such practices and mitigate other risky practices would benefit both the harvested species and the ecosystems in which they are situated.

Additionally, from the selection of species reviewed, more are predominantly or exclusively wild harvested compared to those that are artificially propagated. For some species, such as *Agaricus bisporus*, cultivation is relatively simple with a good yield (Beyer, 2003), however for many species, particularly in the genera *Armillaria, Boletus, Morchella* and *Ophiocordyceps* attempts to artificially propagate specimens at a commercial level have been unsuccessful. This is due to a variety of factors, such as narrow environmental parameters, host specificity, mycorrhizal collapse when transplanted between substrates (equivalent to “potting on” plants) and infection of the crop by insects and bacteria (Beyer *et al.,* 2023; Jess & Bingham, 2007; Pilz *et al.,* 2007; Wang & Chen, 2014; Xu *et al.,* 2022).

The specificity of lichens in requiring multiple algal, yeast and higher fungal partners as well as specific environmental conditions makes reliable artificial propagation highly technically challenging, and the evidence suggests that consequently, all lichens on the international market are likely to have been wild harvested (Grube, 2021).

Where artificial propagation does occur, it is often unclear whether the facilities would meet the requirements for artificial propagation or assisted propagation as defined by Res. Conf. 11 (Rev. CoP18). This is most likely to be due to the lack of record keeping and reporting of the information required by the convention, as there is currently no need for facilities to do so.

Another concern highlighted in this review is the difficulties with fungal nomenclature and life stages. Fungal phylogeny and taxonomy are an evolving discipline, and fungi species frequently undergo re-categorisation as molecular phylogenetic techniques become more affordable and accessible. This presents difficulties for species listings at a practical level toensure common understanding of the scope of taxonomic names for management and scientific authorities as well as users of these species, especially where different names are still used for different life stages under the now abandoned system of dual species nomenclature. Consideration should therefore be given on how to have common and consistent fungal nomenclature for any considerations under CITES.

The international trade in fungi and lichens is vast, however, due to fragmented reporting and limited legislation, most of the international trade is unquantified. This makes it difficult to estimate existing wild populations and whether harvesting for international trade is detrimental to the survival of species. As discussed, there is currently no requirement for trade records to reflect the needs of the Convention so the data recorded is only partially useful for understanding fungal and lichen trade in the context of CITES. Where records do exist, they are useful in recording trade quantities, trade values, and the importing and exporting countries. However, information on specimen source is often lacking. Additionally, there is only quantifiable data for commercial trade;

personal use and scientific specimens are not typically publicly recorded, as there is no requirement to do so for most species unless there is local legislation in place. Although current predictions are that fungal trade is likely to increase (Niego *et al.,* 2023), more research is certainly needed to understand trade patterns in specific fungi and lichen genera, but there is sufficient information available for some fungi taxa already to merit further discussion of appropriate measures to support their ongoing sustainable use and conservation.

This review has also highlighted some of the ecological and biological characteristics associated with traded species that influence the risk associated with international trade. For parasitic genera. such as *Armilliaria, Cordyceps, Fomes* and *Ganoderma*, the requirement for specific hosts severely limits the availability of specimens available for harvesting. This is particularly true of *Ophiocordyceps sinensis*, which can only complete its lifecycle and produce the commercially desirable fruiting bodies by infecting larvae of *Hepialidae* moths in the narrow geographic range of Himalayas and Tibetan plateau (Zhu *et al*., 1998).

Another factor this review highlighted is the narrow geographic ranges that some species in international trade have. For example, individual species of *Morchella* are endemic to small geographic regions (O'Donnell *et al*., 2011). This makes them more at risk of genetic erosion, due to the smaller number of sexually mature individuals, and is a considerable conservation risk. Many of these species are also at risk from shrinking habitats due to climate change and human activity. This is a particular concern for lichens, which are particularly sensitive to environmental changes (Giordani *et al*., 2020). CITES reporting for these fungi and lichens would increase the data on the source and trade patterns of these species, which would assist in population monitoring, as well as the consideration of the effects of harvest on habitats in management plans that affect these species.

Based on the information available for analysis in this review, there is a need for further research and consideration on fungi in international trade and the role of CITES to ensure sustainable management of these resources.

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References

Adanacıoğlu, N., Tan, A., Karabak, S., Aysar, N., Ayas, F. ı, Aykas, L. & Taylan, T. (2017) Economically Important Wild Mushroom Saffron Milk Cap [Lactarius deliciosus (L.) Gray] of Aegean Region, Turkey. 27 91-96.

Akiyama, H., Endo, M., Matsui, T., Katsuda, I., Emi, N., Kawamoto, Y., Koike, T., & Beppu, H. Agaritine from Agaricus blazei Murrill induces apoptosis in the leukemic cell line U937. Biochimica et Biophysica Acta. 2011;1810:519–525.

Amaranthus, M. P., Pilz, D., Moore, A. J., Abbott, R., Luoma, D. L., Powers, R. F., Hauxwell, D. L. & Nakamura, G. M. (2000) American matsutake (Tricholoma magnivelare) across spatial and temporal scales. https://api.semanticscholar.org/CorpusID:128849608.

Amend, A., Fang, Z., Yi, C. & Mcclatchey, W. (2010) Local perceptions of Matsutake mushroom management, in NW Yunnan China. Biological Conservation. 143 165-172. 10.1016/j.biocon.2009.09.022.

Antonelli, A., Fry, C., Smith, R.J., Eden, J., Govaerts, R.H.A., Kersey, P., Lughadha,N., Onstein, E., Simmonds, R.E., Zizka, M.S.J.,... *et al.,* (2023). State of the World's Plants and Fungi 2023. Royal Botanic Gardens, Kew. DOI: https://doi.org/10.34885/wnwn-6s63

Antonyuk, V., Panchak, L. V., Antonyuk, L. Y., & Zyn, A. R. (2021). EXTRACTIVE SUBSTANCES OF FRUIT BODY GOLDEN CHANTERELLE (CANTHARELLUS CIBARIUS FR.) AND HEDGEHOG MUSHROOM (HYDNUM REPANDUM FR.). Emirates Journal of Food and Agriculture, 32(11), 826–834. https://doi.org/10.9755/ejfa.2020.v32.i11.2195

Arnolds, E. (1991) Decline of ectomycorrhizal fungi in Europe. Agriculture, Ecosystems & Environment. 35 (2), 209-244. 10.1016/0167-8809(91)90052-Y.

Arora D, Frank JL (2014). "Clarifying the butter Boletes: a new genus, Butyriboletus, is established to accommodate Boletus sect. Appendiculati, and six new species are described". Mycologia. 106 (3): 464–80. doi:10.3852/13-052

Arora, D. & Dunham, S. (2008) A New, Commercially Valuable Chanterelle Species, Cantharellus californicus sp. nov., Associated with Live Oak in California, USA. Economic Botany. 62 376-391. 10.1007/s12231-008-9042-7.

Asiegbu, F. O., & Kovalchuk, A. (2021). Chapter 1 - An introduction to forest biome and associated microorganisms. In F. O. Asiegbu & A. B. T.-F. M. Kovalchuk (Eds.), *Forest Microbiology* (pp. 3–16). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-822542-4.00009-7

Baby, S., Johnson, A. J. & Govindan, B. (2015) Secondary metabolites from Ganoderma. Phytochemistry. 114 66-101. 10.1016/j.phytochem.2015.03.010.

Bai, H., Wang, Z., Cui, J., Yun, K., Zhang, H., Liu, R. H., Fan, Z., & Cheng, C. (2014). Synergistic Radiation Protective Effect of Purified Auricularia auricular-judae Polysaccharide (AAP IV) with Grape Seed Procyanidins. In *Molecules* (Vol. 19, Issue 12, pp. 20675–20694). https://doi.org/10.3390/molecules191220675

Barroetaveña, C., La Manna, L. & Alonso, M. V. (2008) Variables affecting Suillus luteus fructification in ponderosa pine plantations of Patagonia (Argentina). Forest Ecology and Management. 256 (11), 1868-1874. 10.1016/j.foreco.2008.07.029.

Barron, E.S. and M.R. Emery. (2009). Protecting Resources: Assessing harvesting of wild morel mushrooms in two National Capital Region parks. Natural Resource Technical Report NPS/NCRO/NRTR 2009/002. Department of the Interior, National Park Service, Washington, D.C. 52 p.

Bashir, H., Chen, J., Jabeen, S., Ullah, S., Khan, J., Niazi, A.R., Zhang, M., Khalid, A.N., Parra, L.A., Callac, P. An overview of Agaricus section Hondenses and Agaricus section Xanthodermatei with description of eight new species from Pakistan. Sci Rep. 2021 Jun 18;11(1):12905. doi: 10.1038/s41598-021-92261-5. PMID: 34145323; PMCID: PMC8213768.

Bertault, G., Rousset, F., Fernandez, D., Berthomieu, A., Hochberg, M. E., Callot, G. & Raymond, M. (2001) Population genetics and dynamics of the black truffle in a man-made truffle field. Heredity. 86 (Pt 4), 451-458. 10.1046/j.1365-2540.2001.00855.x.

Bessette, A. E., Smith, D. & Bessette, A. R. (2021). *Polypores and Similar Fungi of Eastern and Central North America*. University of Texas Press. ISBN 978-1-4773-2272-7.

Beyer, D.M. (2003). Basic Procedures for Agaricus Mushroom Growing. Agrichem. Available online https://web.archive.org/web/20070921154907/http://www.americanmushroom.org/agaricus.pdf [Accessed 04/09/2024].

Beyer, D.M.; Wuest, P.J; Anderson, M.G. "Green mold of Mushrooms". Available online at https://extension.psu.edu/green-mold-of-mushrooms [Accessed 04/09/2024].

Bijalwan, A., Dobriyal, M., Thakur, T., Thakur, M. & Bahuguna, K. (2020) Insights ofF medicinal mushroom (Ganoderma lucidum): prospects and potential in India. 10.15406/bij.2020.04.00186.

Boa, E. (2004) Wild Edible Fungi: A Global Overview of Their Use and Importance to People.

Boh, B., Berovic, M., Zhang, J. & Zhi-Bin, L. (2007) Ganoderma lucidum and its pharmaceutically active compounds. Biotechnology Annual Review. 13 265-301. 10.1016/S1387-2656(07)13010-6.

Bong, F., Chie, W., & Abu Seman, I. (2012). Ganoderma Species Associated with Basal Stem Rot Disease of Oil Palm. *American Journal of Applied Sciences*, *9*, 879–885. https://doi.org/10.3844/ajassp.2012.879.885

Bonito, G. M., & Smith, M. E. (2016). General systematic position of the truffles: evolutionary theories. In: Zambonelli, A., Iotti, M., & Murat, C. (Eds.), True truffle (Tuber spp.) in the world (pp. 3–18). Cham: Springer. https://doi.org/10.1007/978-3-319-31436-5_1

Brandrud, T.-E. 2020. Tricholoma matsutake (errata version published in 2022). The IUCN 2020: e.T76267712A223017164. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T76267712A223017164.en. Accessed on 15 September 2023.

Brodo, I. M. & Duran Sharnoff, S. (2001) Lichens of North America. ISBN 978-0300082494.

Bruns, T.D., Bidartondo, M.I., & Taylor, D.L. (2002). Host Specificity in Ectomycorrhizal Communities: What Do the Exceptions Tell Us? Integrative and Comparative Biology, 42: 2. https://doi.org/10.1093/icb/42.2.352

Buchanan, P. 2019. Cordyceps hauturu. The IUCN 2019: e.T154811245A154811312. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T154811245A154811312.en. [Accessed on 15.09.23].

Buchanan, P. & Cooper, J.A. 2019. Ganoderma sp. nov. 'Awaroa'. The IUCN 2019: e.T154926191A154926197. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T154926191A154926197.en. Accessed on 15 September 2023.

Bulam, S., Şule Üstün, N., & Pekşen, A. (2018). The Most Popular Edible Wild Mushrooms in Vezirköprü District of Samsun Province. Turkish Journal of Agriculture - Food Science and Technology, 6(2), 189–194. https://doi.org/10.24925/turjaf.v6i2.189-194.1547

Cai, M., Pettenella, D. & Vidale, E. (2011) Income generation from wild mushrooms in marginal rural areas. Forest Policy and Economics. 13 (3), 221-226. 10.1016/j.forpol.2010.10.001.

Case, N. T., Berman, J., Blehert, D. S., Cramer, R. A., Cuomo, C., Currie, C. R., Ene, I. V., Fisher, M. C., Fritz-Laylin, L. K., Gerstein, A. C., Glass, N. L., Gow, N. A. R., Gurr, S. J., Hittinger, C. T., Hohl, T. M., Iliev, I. D., James, T. Y., Jin, H., Klein, B. S., Kronstad, J. W., ... Chen, N., Zhang, H., Zong, X., Li, S., Wang, J., Wang, Y., & Jin, M. (2020). Polysaccharides from Auricularia auricula: Preparation, structural features and biological activities. *Carbohydrate Polymers*, *247*, 116750. https://doi.org/https://doi.org/10.1016/j.carbpol.2020.116750

Cannon, P.F., & Kirk, P.M. (2007). Fungal Families of the World. Wallingford, UK: CAB International. p. 158. ISBN 978-0-85199-827-5.

Catcheside, P. S. & Catcheside, D. E. A. (2012) Boletus edulis (Boletaceae), a new record for Australia. Journal of the Adelaide Botanic Garden. 25 5-10. http://www.jstor.org/stable/23874508.

Čejka, T., Isaac, E., Oliach, D., Martínez-Peña, F., Egli, S., Thomas, P., Trnka, M., & Büntgen, U. (2022). Risk and reward of the global truffle sector under predicted climate change. *Environmental Research Letters*, *17*. https://doi.org/10.1088/1748-9326/ac47c4

Čejka, T., Trnka, M., Krusic, P. J., Stobbe, U., Oliach, D., Václavík, T., Tegel, W. & Büntgen, U. (2020) Predicted climate change will increase the truffle cultivation potential in central Europe. Scientific Reports. 10 (1), 21281. 10.1038/s41598-020-76177-0.

Chauhan, O., Vijay, V.,Pandey, A., & Semwal, A. (2021). Biochemical and Health Properties of Truffles. *Defence Life Science Journal*. https://doi.org/10.14429/dlsj.6.15659

Ćilerdžić, J.L., Sofrenić, I.V., Tešević, V.V., Brčeski, I.D., Duletić-Laušević, S.N., Vukojević, J.B. and Stajić, M.M. (2018), Neuroprotective Potential and Chemical Profile of Alternatively Cultivated Ganoderma lucidum Basidiocarps. Chem. Biodiversity, 15: e1800036. https://doi.org/10.1002/cbdv.201800036

Conference of the Parties (2002). Twelfth meeting Plenary – Third Session. Available online at https://cites.org/sites/default/files/eng/cop/12/rep/Plen3.PDF [Accessed 28.08.24].

Conference of the Parties Resolution Conference 11.11 (Revised CoP 18). (2019). Available online at https://cites.org/sites/default/files/document/E-Res-11-11-R18_0.pdf [Accessed 04/09/2024].

Cotter T. (2015). Organic Mushroom Farming and Mycoremediation: Simple to Advanced and Experimental Techniques for Indoor and Outdoor Cultivation. Chelsea Green Publishing. p. 281. ISBN 978-1-60358-456-2.

Courtecuisse, R., & Duhem, B. (2013). Champignons de France et d'Europe. Guide Delachaux (in French). Paris: Delachaux & Niestlé. ISBN 978-2-603-02038-8.
Cowen, L. E. (2022). The future of fungi: threats and opportunities. G3 (Bethesda, Md.), 12(11), jkac224. https://doi.org/10.1093/g3journal/jkac224

Dahlberg, A. (2019a). Agaricus arvensis (errata version published in 2022). The IUCN 2019: e.T122090207A222966101. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090207A222966101.en. Accessed on 14 September 2023.

Dahlberg, A. (2019b). Agaricus bitorquis (errata version published in 2022). The IUCN 2019: e.T122090210A222966384. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090210A222966384.en. Accessed on 14 September 2023.

Dahlberg, A. (2019c). Agaricus campestris (errata version published in 2022). The IUCN 2019: e.T122090215A222966644. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090215A222966644.en. Accessed on 14 September 2023.

Dahlberg, A. (2019d). Agaricus sylvaticus (errata version published in 2022). The IUCN 2019: e.T122090218A222966981. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090218A222966981.en. Accessed on 14 September 2023.

Dahlberg, A. (2019e). Albatrellus confluens (errata version published in 2022). The IUCN 2019: e.T122090225A222968204. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090225A222968204.en. Accessed on 14 September 2023.

Dahlberg, A. (2019f). Boletus edulis (errata version published in 2022). The IUCN 2019: e.T122090234A222968388. https://dx.doi.org/10.2305/IUCN.UK.2019-

3.RLTS.T122090234A222968388.en. Accessed on 14 September 2023.

Dahlberg, A. (2019g). Boletus reticulatus (errata version published in 2022). The IUCN 2019: e.T122090240A222968893. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090240A222968893.en. Accessed on 14 September 2023.

Dahlberg, A. (2019h). Boletus pinophilus (errata version published in 2022). The IUCN 2019: e.T122090237A222968707. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090237A222968707.en. Accessed on 14 September 2023.

Dahlberg, A. (2019i). Russula paludosa (errata version published in 2022). The IUCN 2019: e.T122090744A223014568. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090744A223014568.en. Accessed on 15 September 2023.

Dahlberg, A. (2019j). Russula vesca (errata version published in 2022). The IUCN 2019: e.T122090747A223014776. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090747A223014776.en. Accessed on 15 September 2023.

Dahlberg, A.(2019k). Russula aeruginea (errata version published in 2022). The IUCN 2019: e.T122090725A223013899. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090725A223013899.en. Accessed on 15 September 2023.

Dahlberg, A. (2019l). Russula decolorans (errata version published in 2022). The IUCN 2019: e.T122090737A223014355. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090737A223014355.en. Accessed on 15 September 2023.

Dahlberg, A. (2019m). Russula vinosa (errata version published in 2022). The IUCN 2019: e.T122090750A223015039. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090750A223015039.en. Accessed on 15 September 2023.

Dahlberg, A. (2019n). Russula claroflava (errata version published in 2022). The IUCN 2019: e.T122090728A223014116. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090728A223014116.en. Accessed on 15 September 2023.

Dahlberg, A. (2019o). Suillus grevillei (errata version published in 2022). The IUCN 2019: e.T122090805A223016083. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090805A223016083.en. Accessed on 15 September 2023.

Dahlberg, A. (2019p). Suillus variegatus (errata version published in 2022). The IUCN 2019: e.T122090821A223016711. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090821A223016711.en. Accessed on 15 September 2023.

Dahlberg, A. (2019q). Suillus granulatus (errata version published in 2022). The IUCN 2019: e.T122090798A223015752. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090798A223015752.en. Accessed on 15 September 2023.

Dahlberg, A. (2019r). Suillus luteus (errata version published in 2022). The IUCN 2019: e.T122090818A223016348. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090818A223016348.en. Accessed on 15 September 2023.

Dahlberg, A. (2019s). Suillus luteus (errata version published in 2022). The IUCN 2019: e.T122090818A223016348. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T122090818A223016348.en. Accessed on 15 September 2023.

Dahlman, M., Danell, E., & Spatafora, J. W. (2000). Molecular systematics of Craterellus: cladistic analysis of nuclear LSU rDNA sequence data. *Mycological Research*, *104*(4), 388–394. https://doi.org/https://doi.org/10.1017/S0953756299001380

Dahlstrom, J.L., Smith, J.E., & Weber, N.S. (2000). "Mycorrhiza-like interaction by Morchella with species of the Pinaceae in pure culture synthesis". Mycorrhiza. 9 (5): 279–285. doi:10.1007/PL00009992

Daley, J. (2018). "This Humongous Fungus Is as Massive as Three Blue Whales". *Smithsonian.com*. Smithsonian Institution.

Danell, E. & Camacho, F. J. (1997) Successful cultivation of the golden chanterelle. Nature. 385 (6614), 303. 10.1038/385303a0.

Daniel, G.H., & Polanin, N. (2013). Tree Dwelling Lichens. New Jersey Agricultural Station. Available online at https://njaes.rutgers.edu/fs1205/ [Accessed 07/08/2024].

Das, S. K., Masuda, M., Sakurai, A. & Sakakibara, M. (2010) Medicinal uses of the mushroom Cordyceps militaris: current state and prospects. Fitoterapia. 81 (8), 961-968. 10.1016/j.fitote.2010.07.010.

de Frutos, P. (2020) Changes in world patterns of wild edible mushrooms use measured through international trade flows. Forest Policy and Economics. 112 102093. 10.1016/j.forpol.2020.102093.

Dema, S. (2021). Chinese Caterpillar Fungus (*Ophiocordyceps sinensis*). Available at https://www.inaturalist.org/photos/145344394 [Accessed 02/09/2024].

Dentinger, B. T. M., Ammirati, J. F., Both, E. E., Desjardin, D. E., Halling, R. E., Henkel, T. W., Moreau, P., Nagasawa, E., Soytong, K., Taylor, A. F., Watling, R., Moncalvo, J. & McLaughlin, D. J. (2010) Molecular phylogenetics of porcini mushrooms (Boletus section Boletus). Molecular Phylogenetics and Evolution. 57 (3), 1276-1292. 10.1016/j.ympev.2010.10.004.

Devkota, P., & Hammerschmidt, R. (2020). The infection process of Armillaria mellea and Armillaria solidipes. *Physiological and Molecular Plant Pathology*, *112*, 101543. https://doi.org/https://doi.org/10.1016/j.pmpp.2020.101543

Devkota, S., Chaudhary, R., Werth, S., & Scheidegger, C. (2017). Trade and legislation: Consequences for the conservation of lichens in the Nepal Himalaya. *Biodiversity and Conservation*, *26*, 2491–2505. https://doi.org/10.1007/s10531-017-1371-3

Dias, E., Abe, C. & Schwan, R. (2004) Truths and myths about the mushroom Agaricus blazei. Scientia Agricola. 61 10.1590/S0103-90162004000500014.
Dobson, F.S. (2011). Lichens, an illustrated guide to the British and Irish species. Slough, UK: Richmond Publishing Co. ISBN 9780855463151.

Dunham, S. M., O'Dell, T. E., & Molina, R. (2006). Spatial analysis of within-population microsatellite variability reveals restricted gene flow in the Pacific golden chanterelle (Cantharellus formosus). Mycologia, 98(2), 250–259. https://doi.org/10.3852/mycologia.98.2.250

Dyson, L. B., Herpel, R., Karasch, P., Müller, J., Thom, D., & Bässler, C. (2024). Effects of forest management on the key fungal decomposer Fomes fomentarius in European beech forests – Lessons from a large-scale experiment. *Forest Ecology and Management*, *552*, 121580. https://doi.org/https://doi.org/10.1016/j.foreco.2023.121580

Egli, S., Peter, M., Buser, C., Stahel, W. & Ayer, F. (2006) Mushroom picking does not impair future harvests – results of a long-term study in Switzerland. Biological Conservation. 129 (2), 271-276. 10.1016/j.biocon.2005.10.042.

Ehlers, T. & Hobby, T. (2010) The chanterelle mushroom harvest on northern Vancouver Island, British Columbia: Factors relating to successful commercial development. Journal of Ecosystems and Management. 11 72-83. https://api.semanticscholar.org/CorpusID:127802790.

Elkhateeb, W., & Daba, G. (2022). *Bioluminescent Mushrooms: Boon for Environmental Health*. *1*, 88–97. https://doi.org/10.5281/zenodo.7198885

Ellis, J.B., & Ellis, M.B. (1990). Fungi without Gills (Hymenomycetes and Gasteromycetes): an Identification Handbook. London, UK: Chapman and Hall. pp. 102–3. ISBN 978-0-412-36970-4.

Endo M., Beppu H., Akiyama H., Wakamatsu K., Ito S., Kawamoto Y., Shimpo K., Sumiya T., Koike T., Matsui T. Agaritine purified from Agaricus blazei Murrill exerts anti-tumor activity against leukemic cells. Biochimica Biophysica Acta. 2010;1800:669–673.

Erbiai, E. H., Pinto da Silva, L., Saidi, R., Lamrani, Z., Silva, J. & Maouni, A. (2021) Chemical Composition, Bioactive Compounds and Antioxidant Activity of Two Wild Edible Mushrooms Armillaria mellea and Macrolepiota procera from Two Countries (Morocco and Portugal). Biomolecules. 11 575. 10.3390/biom11040575.

European Medicines Agency. (2014). Assessment report on *Cetraria islandica* (L.) Acharius s.l., thallus. Available online at https://www.ema.europa.eu/en/documents/herbal-report/final-assessment-report-cetraria-islandica-l-acharius-sl-thallus-first-version_en.pdf [Accessed 19.08.24].

Fadhilah A, Gabbar A, Bokhari AA. Microsporidium. (2023). In: StatPearls. Treasure Island (FL). Available from: https://www.ncbi.nlm.nih.gov/books/NBK537166/ [Accessed 09/08/24].

FairWild. (2021). Available online https://www.fairwild.org/news/2021/10/07/fairwild-foundation-launches-technical-consultation-for-fungi [Accessed 28/08/24].

Feng, B., Wang, X. H., Ratkowsky, D., Gates, G., Lee, S. S., Grebenc, T., & Yang, Z. L. (2016). Multilocus phylogenetic analyses reveal unexpected abundant diversity and significant disjunct distribution pattern of the Hedgehog Mushrooms (Hydnum L.). Scientific reports, 6, 25586. https://doi.org/10.1038/srep25586

Feng, B., Xu, J., Wu, G., Zeng, N.-K., Li, Y.-C., Tolgor, B., Kost, G. W., & Yang, Z. L. (2012). DNA Sequence Analyses Reveal Abundant Diversity, Endemism and Evidence for Asian Origin of the Porcini Mushrooms. PLOS ONE, 7(5), e37567. https://doi.org/10.1371/journal.pone.0037567

Fernandes EG, Valério HM, Feltrin T, Van Der Sand ST (2012). "Variability in the production of extracellular enzymes by entomopathogenic fungi grown on different substrates". Braz. J. Microbiol. 43 (2): 827–33. doi:10.1590/S1517-83822012000200049

FlyDressing. (2024). Available online at https://flydressing.se/produkt/amadou-sheet/ Accessed [02/09/2024].

Fordjour, E., Manful, C. F., Javed, R., Galagedara, L. W., Cuss, C. W., Cheema, M., & Thomas, R. (2023). Chaga mushroom: a super-fungus with countless facets and untapped potential. Frontiers in pharmacology, 14, 1273786. https://doi.org/10.3389/fphar.2023.1273786

Furci, G. 2019. Butyriboletus loyo. The IUCN 2019: e.T75099337A75099440. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T75099337A75099440.en

Ganeshpurkar, A., Rai, G., & Jain, A. P. (2010). Medicinal mushrooms: Towards a new horizon. Pharmacognosy Reviews, 4(8), 127.

Garcia-Barreda, S., Forcadell, R., Sánchez, S., Martín-Santafé, M., Marco, P., Camarero, J. J. & Reyna, S. (2018) Black Truffle Harvesting in Spanish Forests: Trends, Current Policies and Practices, and Implications on its Sustainability. Environmental Management. 61 (4), 535-544. 10.1007/s00267-017-0973-6.

Gariboldi, M. B., Marras, E., Ferrario, N., Vivona, V., Prini, P., Vignati, F., & Perletti, G. (2023). Anti-carcinogenic Potential of Edible/Medicinal Mushrooms in Breast Cancer. International journal of molecular sciences, 24(12), 10120. https://doi.org/10.3390/ijms241210120

Geml, J., Laursen, G.A., Timling, I., McFarland, J.M., Booth, M.G., Lennon, N., Nusbaum, C., & Tayler, D.L. (2009). "Molecular phylogenetic biodiversity assessment of arctic and boreal ectomycorrhizal Lactarius Pers. (Russulales; Basidiomycota) in Alaska, based on soil and sporocarp DNA" (PDF). Molecular Ecology. 18 (10): 2213–2227. doi:10.1111/j.1365-294X.2009.04192.x.

Giordani, P., Benesperi, R., Bianchi, E., Malaspina, P., Nascimbene, J. (2020). Threats and Conservation Strategies for Overlooked Organisms: The Case of Epiphytic Lichens. In: Shukla, V., Kumar, N. (eds) Environmental Concerns and Sustainable Development. Springer, Singapore. https://doi.org/10.1007/978-981-13-6358-0_1

Gleason, F.H., Scholz, B., Jephcott, T.G., van Ogtrop, F.F., Henderson, L., Lilje, O., Kittelmann, S., Macarthur, D.J. (2017). Key Ecological Roles for Zoosporic True Fungi in Aquatic Habitats. Microbiol Spectr 5:10 https://doi.org/10.1128/microbiolspec.funk-0038-2016

Gonçalves, S.C. 2019. Amanita caesarea. The IUCN 2019: e.T125433663A125435485. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T125433663A125435485.en. Accessed on 14 September 2023.

Greene, D.F., Hesketh, M., & Pounden, E. (2010). "Emergence of morel (Morchella) and pixie cup (Geopyxis carbonaria) ascocarps in response to the intensity of forest floor combustion during a wildfire". Mycologia. 102 (4): 766–773. doi:10.3852/08-096

Grimm, M., Grube, M., Schiefelbein, U., Zühlke, D., Bernhardt, J., & Riedel, K. (2021). The Lichens' Microbiota, Still a Mystery?. Frontiers in microbiology, 12, 623839. https://doi.org/10.3389/fmicb.2021.623839

Grube. M. (2021). Lichens – Growing Greenhouses *en miniature*. Microbial Cell **8**:3, pp 65-68. doi: 10.15698/mic2021.03.743

Guerin-Laguette, A., Cummings, N., Butler, R., Willows, A., Hesom-Williams, N., Li, S. & Wang, Y. (2014) Lactarius deliciosus and Pinus radiata in New Zealand: towards the development of innovative gourmet mushroom orchards. Mycorrhiza. 24 511-523. 10.1007/s00572-014-0570-y.

Guo, Y., Zhao, Z., Wei, H., Gao, B. & Gu, W. (2017) Prediction of the potential geographic distribution of the ectomycorrhizal mushroom Tricholoma matsutake under multiple climate change scenarios. Scientific Reports. 7 46221. 10.1038/srep46221.

Hall, K., Lemmond, B., & Smith, M. E. (2023). The Common Chanterelles (Cantharellus and Craterellus) of Florida: PP369/PP369, 2/2023. EDIS, 2023(1). https://doi.org/10.32473/edis-pp369-2023

Hall, I. R., Yun, W. & Amicucci, A. (2003) Cultivation of edible ectomycorrhizal mushrooms. Trends in Biotechnology. 21 (10), 433-438. 10.1016/S0167-7799(03)00204-X.

Hall, I. R., Lyon, A. J. E., Wang, Y., & Sinclair, L. (1998). Ectomycorrhizal fungi with edible fruiting bodies 2.Boletus edulis. Economic Botany, 52(1), 44–56. https://doi.org/10.1007/BF02861294

Halpern, M. (2002). Medicinal Mushrooms. New York, New York: M. Evans and Company, Inc. pp. 64–65. ISBN 978-0-87131-981-4

Harrington, T., & Cullen, M. (2008). Assessment of wild edible fungal production in Irish woodlands. *Silviculture Management*. Coford Connects. **16.**

Hawksworth, D. L., & Grube, M. (2020). Lichens redefined as complex ecosystems. The New phytologist, 227(5), 1281–1283. https://doi.org/10.1111/nph.16630

Hawksworth D (2011) A new dawn for the naming of fungi: impacts of decisions made in Melbourne in July 2011 on the future publication and regulation of fungal names. MycoKeys 1: 7-20. https://doi.org/10.3897/mycokeys.1.2062

He, X., Wang, X., Fang, J., Chang, Y., Ning, N., Guo, H., Huang, L., Huang, X. & Zhao, Z. (2017) Structures, biological activities, and industrial applications of the polysaccharides from Hericium erinaceus (Lion's Mane) mushroom: A review. International Journal of Biological Macromolecules. 97 228-237. 10.1016/j.ijbiomac.2017.01.040.

Henning, L. M., Simon, U., Abdullayev, A., Schmidt, B., Pohl, C., Nunez Guitar, T., Vakifahmetoglu, C., Meyer, V., Bekheet, M. F., & Gurlo, A. (2022). Effect of Fomes fomentarius Cultivation Conditions on Its Adsorption Performance for Anionic and Cationic Dyes. *ACS Omega*, *7*(5), 4158–4169. https://doi.org/10.1021/acsomega.1c05748

Hinsley, A., Challender, D. W. S., Masters, S., Macdonald, D. W., Milner-Gulland, E. J., Fraser, J., & Wright, J. (2024). Early warning of trends in commercial wildlife trade through novel machine-learning analysis of patent filing. *Nature Communications*, *15*(1), 6379. https://doi.org/10.1038/s41467-024-49688-x

Hitchmough, R. (2002). New Zealand Threat Classification System lists 2002. Threatened Species Occasional Publications 23. Wellington, Department of Conservation. 210 pp.

Hosford, D., Pilz, D., Molina, R. & Amaranthus, M. (1997) Ecology and management of the commercially harvested American matsutake. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

IUCN. 2024. The IUCN. Version 2022-2. https://www.iucnredlist.org. Accessed on [01/08/2024].

Jagadish, L.K., Venkata Krishnan, V., Shenbhagaraman, R., & Kaviyarasan, V. (2009). Comparitive study on the antioxidant, anticancer and antimicrobial property [sic] of Agaricus bisporus (J. E. Lang) Imbach before and after boiling. African Journal of Biotechnology Vol. 8 (4), pp. 654-661.

Jaichaliaw, C., Kumla, J., Vadthanarat, S., Suwannarach, N., & Lumyong, S. (2021). Multigene Phylogeny and Morphology Reveal Three Novel Species and a Novel Record of Agaricus From Northern Thailand. Frontiers in microbiology, 12, 650513. https://doi.org/10.3389/fmicb.2021.650513

Janda, V., Kříž, M., & Kolarik, M. (2019). Butyriboletus regius and Butyriboletus fechtneri: Typification of two well-known species. *Czech Mycology*, *71*, 1–32. https://doi.org/10.33585/cmy.71101

Jeong, Y., Yang, B., Jeong, S., Kim, S. & Song, C. (2008) Ganoderma applanatum: a promising mushroom for anti-tumour and immunomodulating activity. Phytotherapy Research : PTR. 22 (5), 614-619. 10.1002/ptr.2294.

Jess, S., & Bingham, J. F. W. (2004). Biological control of sciarid and phorid pests of mushroom with predatory mites from the genus Hypoaspis (Acari: Hypoaspidae) and the entomopathogenic nematode Steinernema feltiae. *Bulletin of Entomological Research*, *94*(2), 159–167. doi:10.1079/BER2003286

Johnston, E. (2022). What in Earth? Understanding What Fungi Really Are. Available online at https://www.kew.org/read-and-watch/whats-a-fungi [Accessed 09/08/24].

Johnston, E., & Brewer, G. (2023). Mycelium: Exploring the hidden dimension of fungi. Available online at https://www.kew.org/read-and-watch/fungi-hidden-dimension [Accessed 09/08/24].

Jones Medlin, J. & Jain, B. (1996). Michigan Lichens. Wayback Machine. ISBN 0877370397 Archived 24/11/2016.

Kadnikova, I., Costa, R., Kalenik, T., Guruleva, O. & Yanguo, S. (2015) Chemical Composition and Nutritional Value of the Mushroom Auricularia auricula-judae. Journal of Food and Nutrition Research. 3 478-482. 10.12691/jfnr-3-8-1.

Kałucka, I.L. & Olariaga Ibarguren, I. 2019. Hericium erinaceus. The IUCN 2019: e.T70401627A70401637. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T70401627A70401637.en. Accessed on 15 September 2023.

Karakaya, F., BİLGİLİ, C., SOYSAL, N., & Yılmaz, M. (2023). Investigation of secondary school students' learning about the fungi kingdom. *Turkish Journal of Education*, *12*, 227–242. https://doi.org/10.19128/turje.1334348il

Ke, H.-M., & Tsai, I. J. (2022). Understanding and using fungal bioluminescence – Recent progress and future perspectives. *Current Opinion in Green and Sustainable Chemistry*, *33*, 100570. https://doi.org/https://doi.org/10.1016/j.cogsc.2021.100570

Kibby, G. (2003). Mushrooms and Toadstools of Britain and Northern Europe. Hamlyn. p. 213. ISBN 978-0-7537-1865-0

Kirk, P.M., Cannon, P.F., Minter, D.W., & Stalpers, J.A. (2008). Dictionary of the Fungi (10th ed.). Wallingford, UK: CABI. p. 483. ISBN 978-0-85199-826-8

Klein, J. (2019). "In the Race to Live on Land, Lichens Didn't Beat Plants". The New York Times.

Klein, A. (2018). "Vegan-friendly fashion is actually bad for the environment". New Scientist.

Kligman, A. M. (1943) Some Cultural and Genetic Problems in the Cultivation of the Mushroom, Agaricus campestris Fr. American Journal of Botany. 30 (10), 745-763. 10.2307/2437548.

Kuo, M., Dewsbury, D.R., O'Donnell, K., Carter, M.C., Rehner, S.A., Moore, J.D., Moncalvo, J.M., Canfield, S.A., Stephenson, S.L., Methven, A.S., & Volk, T.J. (2012). "Taxonomic revision of true morels (Morchella) in Canada and the United States". Mycologia. 104 (5): 1159–1177. doi:10.3852/11-375

Landesamt für Natur, Umwelt und Verbraucherschutz. (2017). Press Release – Collecting Mushrooms – now? Available at https://www.lanuv.nrw.de/fileadmin/lanuv/presse/dokumente/PM_LANUV_Pilze_21_08_2017.pdf [Accessed 07/05/2024].

Lannoy, G., & Estadès, A. (2001). Les Bolets. Flore mycologique d'Europe. Documents Mycologiques Mémoire Hors série no. 6 (in French). Lille, France: Association d'Écologie et de Mycologie. pp. 1–163.

Laperriere, G., Desgagné-Penix, I. & Germain, H. (2018) DNA distribution pattern and metabolite profile of wild edible lobster mushroom (Hypomyces lactifluorum/Russula brevipes). Genome. 61 (5), 329-336. 10.1139/gen-2017-0168.

Larson, A. J., Cansler, C. A., Cowdery, S. G., Hiebert, S., Furniss, T. J., Swanson, M. E. & Lutz, J. A. (2016) Post-fire morel (Morchella) mushroom abundance, spatial structure, and harvest sustainability. Forest Ecology and Management. 377 16-25. 10.1016/j.foreco.2016.06.038.

Lee, M., Hur, H., Chang, K., Lee, T., Ka, K. & Jankovsky, L. (2008) Introduction to Distribution and Ecology of Sterile Conks of Inonotus obliquus. Mycobiology. 36 199-202. 10.4489/MYCO.2008.36.4.199.

Leiva, F. J., Saenz-Díez, J. C., Martínez, E., Jiménez, E. & Blanco, J. (2015) Environmental impact of Agaricus bisporus cultivation process. European Journal of Agronomy. 71 141-148. 10.1016/j.eja.2015.09.013.

Leonardi, M., Comandini, O., Sanjust, E. & Rinaldi, A. (2021) Conservation Status of Milkcaps (Basidiomycota, Russulales, Russulaceae), with Notes on Poorly Known Species. Sustainability. 13 10365. 10.3390/su131810365.

Leonardo-Silva, L., Abdel-Azeem, A. M., & Xavier-Santos, S. (2021). Inonotus rickii (Agaricomycetes, Hymenochaetaceae) in Brazilian Cerrado: Expanding Its Geographic Distribution and Host List. *Frontiers in Microbiology*, *12*. https://www.frontiersin.org/journals/microbiology/articles/10.3389/fmicb.2021.647920

León, H., Morales, P., Bonilla, M., Aguilar, A., González, E., Carrera, D., Gómez, M., Ramírez, P., Largo, A. & Ortega, P. (2002) Studies on the traditional management, and processing of matsutake mushrooms In Oaxaca, Mexico. Micología Aplicada International. 14 25-43.

Lepp, H. (2011). "What is a lichen?". Australian National Botanic Gardens. Archived from the original on 2 July 2014

Li H, Wei H, Peng H, Ding H, Wang L, He L, Fu L (2014). "Boletus roseoflavus, a new species of Boletus in section Appendiculati from China". Mycological Progress. 13 (1): 21–31. doi:10.1007/s11557-013-0888-4

Llarena-Hernández, C.,R., Largeteau, M. L., Ferrer, N., Regnault-Roger, C. & Savoie, J. (2014) Optimization of the cultivation conditions for mushroom production with European wild strains of Agaricus subrufescens and Brazilian cultivars. Journal of the Science of Food and Agriculture. 94 (1), 77-84. 10.1002/jsfa.6200.

Lo, H. C., Hsieh, C., Lin, F. Y., & Hsu, T. H. (2013). A Systematic Review of the Mysterious Caterpillar Fungus Ophiocordyceps sinensis in Dong-ChongXiaCao (Dōng Chóng Xià Cǎo) and Related Bioactive Ingredients. Journal of traditional and complementary medicine, 3(1), 16–32. https://doi.org/10.4103/2225-4110.106538

Loizides M, Alvarado P, Clowez P, Moreau PA, de la Osa LR, Palazon A (2015). "Morchella tridentina, M. rufobrunnea, and M. kakiicolor: a study of three poorly known Mediterranean morels, with nomenclatural updates in section Distantes". Mycological Progress. 14 (13). doi:10.1007/s11557-015-1030-6

Loyd, A. L., Richter, B. S., Jusino, M. A., Truong, C., Smith, M. E., Blanchette, R. A., & Smith, J. A. (2018). Identifying the "Mushroom of Immortality": Assessing the Ganoderma Species Composition in Commercial Reishi Products. Frontiers in microbiology, 9, 1557. https://doi.org/10.3389/fmicb.2018.01557

Lu, Y., Zhi, Y., Miyakawa, T. & Tanokura, M. (2019) Metabolic profiling of natural and cultured Cordyceps by NMR spectroscopy. Scientific Reports. 9 10.1038/s41598-019-44154-x.

Lu, L.-X., Yao, F.-J., Wang, P., Fang, M., Zhang, Y.-M., Zhang, W.-T., Kong, X.-H., & Lu, J. (2017). Construction of a genetic linkage map and QTL mapping of agronomic traits in Auricularia auricula-judae. *Journal of Microbiology*, *55*(10), 792–799. https://doi.org/10.1007/s12275-017-7241-6

Lücking, R., Hodkinson, B.P. & Leavitt, S. D. (2017). "The 2016 classification of lichenized fungi in the Ascomycota and Basidiomycota–Approaching one thousand genera". The Bryologist. 119 (4): 361–416. doi:10.1639/0007-2745-119.4.361

Luo, Q., Yang, X., Yang, Z., Tu, Z. & Cheng, Y. (2016) Miscellaneous meroterpenoids from Ganoderma applanatum. Tetrahedron. 72 (30), 4564-4574. 10.1016/j.tet.2016.06.019.

Luoma, D. L., Eberhart, J. L., Abbott, R., Moore, A., Amaranthus, M. P. & Pilz, D. (2006) Effects of mushroom harvest technique on subsequent American matsutake production. Forest Ecology and Management. 236 (1), 65-75. 10.1016/j.foreco.2006.08.342.

Lung, M. & Chang, Y. (2011) Antioxidant properties of the edible Basidiomycete Armillaria mellea in submerged cultures. International Journal of Molecular Sciences. 12 (10), 6367-6384. 10.3390/ijms12106367.

Malone, T., Swinton, S. M., Pudasainee, A. & Bonito, G. (2022) Economic Assessment of Morel (Morchella spp.) Foraging in Michigan, USA. Economic Botany. 76 (1), 1-15. 10.1007/s12231-022-09548-5.

Maraseni, T.N., & Shivakoti, G.P. (2003) Policy needs in harvesting and marketing of non-timber forest products in Nepal. In: Hiremath AJ, Gladwi C, Uma Shankar R (eds) Proceedings of the South Asian Regional workshop on Policies, Utilisation and Conservation of Non Timber Forest Products in South Asia Region, 28–30 April 2003, Bangalore, India. pp 241–252

Matsutake Worlds, R. G. (2009) A New Form of Collaboration in Cultural Anthropology: Matsutake worlds. American Ethnologist. 36 (2), 380-403. http://www.jstor.org/stable/27667568.

Matthews, R.F. (1993). Cetraria islandica. In: Fire Effects Information System,
U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station,
Fire Sciences Laboratory (Producer). Available online at www.fs.usda.gov/database/feis/lichens/cetisl/all.html [Accessed 20.08.24].

Maurice, S., Arnault, G., Nordén, J., Botnen, S. S., Miettinen, O., & Kauserud, H. (2021). Fungal sporocarps house diverse and host-specific communities of fungicolous fungi. *The ISME Journal*, *15*(5), 1445–1457. https://doi.org/10.1038/s41396-020-00862-1

Mawar, R., Ram, L., Deepesh, & Mathur, T. (2020). Chapter 31—Ganoderma. In N. Amaresan, M. Senthil Kumar, K. Annapurna, K. Kumar, & A. Sankaranarayanan (Eds.), *Beneficial Microbes in Agro-Ecology* (pp. 625–649). Academic Press. https://doi.org/10.1016/B978-0-12-823414-3.00031-9

May, T.W., Cooper, J.A., Dahlberg, A., Furci, G., Minter, D.W., Mueller, G.M., Pouliot, A. and Yang, Z. (2019), Recognition of the discipline of conservation mycology. Conservation Biology, 33: 733-736. https://doi.org/10.1111/cobi.13228

Miao, J., Regenstein, J. M., Qiu, J., Zhang, J., Zhang, X., Li, H., Zhang, H. & Wang, Z. (2020) Isolation, structural characterization and bioactivities of polysaccharides and its derivatives from Auricularia-A review. International Journal of Biological Macromolecules. 150 102-113. 10.1016/j.ijbiomac.2020.02.054.

Miina, J., Peltola, R., Veteli, P., Linnakoski, R., Escribano, M. C., Haveri-Heikkilä, J., Mattila, P., Marnila, P., Pihlava, J., Hellström, J., Sarjala, T., Silvan, N., Kurttila, M. & Vanhanen, H. (2021) Inoculation success of Inonotus obliquus in living birch (Betula spp.). Forest Ecology and Management. 492 119244. 10.1016/j.foreco.2021.119244.

Ministarstvo Zaštite Okoliša I Prostornog Uređenja. (2002). Rulebook on the Protection of Mushrooms and Fungi (translated). Available at https://narodne-novine.nn.hr/clanci/sluzbeni/2002_04_34_739.html [Accessed 07/05/2024].

Miriam de Román & Boa, E. (2006) The Marketing of Lactarius deliciosus in Northern Spain. Economic Botany. 60 (3), 284-290. http://www.jstor.org/stable/4257117.

Mishra, S., Stany, B., & Ravi, L. (2023). Chapter 14—Bacterial symbiosis in edible mushrooms. In D. Dharumadurai (Ed.), *Microbial Symbionts* (pp. 263–276). Academic Press. https://doi.org/10.1016/B978-0-323-99334-0.00014-1

Molina, R., Horton, T.R., Trappe, J.M., & Marcot, B.G. (2011). Addressing uncertainty: How to conserve and manage rare or little-known fungi. Fungal Ecology. 4:11. Pp 134-146. https://doi.org/10.1016/j.funeco.2010.06.003

Molina, R., O'Dell, T., Luoma, D., Amaranthus, M., Castellano, M., Russell, K. & Service, F. (1993) Biology Ecology and Social Aspects of Wild Edible Mushrooms in the Forests of the Pacific Northwest: A Preface to Managing Commercial.

Monaco, P., Naclerio, G., Mello, A. & Bucci, A. (2022) Role and potentialities of bacteria associated with Tuber magnatum: A mini-review. Frontiers in Microbiology. 13 1017089. 10.3389/fmicb.2022.1017089.

Mukai, H., Watanabe, T., Ando, M., & Katsumata, N. (2007). An Alternative Medicine, Agaricus blazei, May Have Induced Severe Hepatic Dysfunction in Cancer Patients. Japanese journal of clinical oncology. 36. 808-10. 10.1093/jjco/hyl108.

Mullins, S. (2024). Lichens on a Rock. Available at https://www.sciencephoto.com/media/16693/view [Accessed 02/09/2024].

Mumcu Kucuker, D. & Baskent, E. Z. (2019) Modeling the productivity of commercial Lactarius mushrooms: A case study in the Kizilcasu planning unit, Turkey. Natural Resource Modeling. 32 (1), e12178. 10.1111/nrm.12178.

Muszyńska, B., Kała, K., Firlej, A. & Sułkowska-Ziaja, K. (2016) Cantharellus Cibarius - Culinary-Medicinal Mushroom Content and Biological Activity. Acta Poloniae Pharmaceutica. 73 (3), 589-598.
Naranjo-Ortiz, M.A. and Gabaldón, T. (2019), Fungal evolution: diversity, taxonomy and phylogeny of the Fungi. Biol Rev, 94: 2101-2137. https://doi.org/10.1111/brv.12550

Nelsen, M. P., Leavitt, S. D., Heller, K., Muggia, L., & Lumbsch, H. T. (2022). Contrasting Patterns of Climatic Niche Divergence in Trebouxia—A Clade of Lichen-Forming Algae. *Frontiers in Microbiology*, *13*. https://www.frontiersin.org/journals/microbiology/articles/10.3389/fmicb.2022.791546

Nikoh, N (2000). Interkingdom host jumping underground: phylogenetic analysis of entomoparasitic fungus of the genus cordyceps. Mol Biol Evol. 17 (4): 629–38. doi:10.1093/oxfordjournals.molbev.a026341

Niego, A.G.T., Lambert, C., Mortimer, P., Thongklang, M., Rapior, S., Grosse, M., Schrey, H., Charria-Girón, E., Walker, A., Hyde, K.D., & Stadler, M. (2023) The contribution of fungi to the global economy. Fungal Diversity 121, 95–137. https://doi.org/10.1007/s13225-023-00520-9

Niskanen, T., Liimatainen, K., Nuytinck, J., Kirk, P., Ibarguren, I. O., Garibay-Orijel, R., … Tedersoo, L. (2018). Identifying and naming the currently known diversity of the genus Hydnum, with an emphasis on European and North American taxa. Mycologia, 110(5), 890–918. https://doi.org/10.1080/00275514.2018.1477004

Norvell, L., Kopecky, F., Lindgren, J. & Roger, J. (2016) The Chanterelle (Cantharellus cibarius): A Peek at Productivity.
Nxumalo, W., Elateeq, A. A. & Sun, Y. (2020) Can Cordyceps cicadae be used as an alternative to Cordyceps militaris and Cordyceps sinensis? - A review. Journal of Ethnopharmacology. 257 112879. 10.1016/j.jep.2020.112879.

O'Donnell, K., Rooney, A.P., Mills, G.L., Kuo, M., Weber, N.S., & Rehner, S.A. (2011). "Phylogeny and historical biogeography of true morels (Morchella) reveals an early Cretaceous origin and high continental endemism and provincialism in the Holarctic". Fungal Genetics and Biology. 48 (3): 252–265. doi:10.1016/j.fgb.2010.09.006

O'Reilly, P. (2011). *Fascinated by Fungi* 2nd Edition. Coch-y-Bonddu Books, Powys. ISBN: 190478447X
Obase, K., Yamanaka, S., Kinoshita, A., Tamai, Y., & Yamanaka, T. (2021). Phylogenetic placements and cultural characteristics of Tuber species isolated from ectomycorrhizas. Mycoscience, 62(2), 124–131. https://doi.org/10.47371/mycosci.2020.12.001

Ogawa, W., Endo, N., Fukuda, M. & Yamada, A. (2018) Phylogenetic analyses of Japanese golden chanterelles and a new species description, Cantharellus anzutake sp. nov. Mycoscience. 59 (2), 153-165. 10.1016/j.myc.2017.08.014.

Oh, Y. L., Choi, I. G., Kong, W. S., Jang, K. Y., Oh, M. J., & Im, J. H. (2020). Evaluating Genetic Diversity of Agaricus bisporus Accessions through Phylogenetic Analysis Using Single-Nucleotide Polymorphism (SNP) Markers. Mycobiology, 49(1), 61–68. https://doi.org/10.1080/12298093.2020.1850172

Oksanen, I. (2006). "Ecological and biotechnological aspects of lichens". Applied Microbiology and Biotechnology. 73 (4): 723–734. doi:10.1007/s00253-006-0611-3.

Outhwaite, C. L., Gregory, R. D., Chandler, R. E., Collen, B., & Isaac, N. J. B. (2020). Complex long-term biodiversity change among invertebrates, bryophytes and lichens. *Nature Ecology & Evolution*, *4*(3), 384–392. https://doi.org/10.1038/s41559-020-1111-z

Ouzouni, P. K., Petridis, D., Koller, W. & Riganakos, K. A. (2009) Nutritional value and metal content of wild edible mushrooms collected from West Macedonia and Epirus, Greece. Food Chemistry. 115 (4), 1575-1580. 10.1016/j.foodchem.2009.02.014.

Panicker, S. (2017). Cordyceps the Fungal Gold - A Review. Advances in Research, 11(3), 1–16. https://doi.org/10.9734/AIR/2017/35923

Paterson, R. R. M. (2006) Ganoderma - a therapeutic fungal biofactory. Phytochemistry. 67 (18), 1985-2001. 10.1016/j.phytochem.2006.07.004.

Pegler D. (2001). "Useful fungi of the world: Amadou and Chaga". Mycologist. 15 (4): 153–154. doi:10.1016/S0269-915X(01)80004-5

Pegler D.N. (2000). "Taxonomy, nomenclature and description of Armillaria". In Fox RTV (ed.). Armillaria Root Rot: Biology and Control of Honey Fungus. Intercept. pp. 81–93. ISBN 1-898298-64-5.

Pelkonen, R., Alfthan, G. & Järvinen, O. (2008) Element concentrations in wild edible mushrooms in Finland. Finnish Environment Institute. http://hdl.handle.net/10138/38380.

Perkins, P. (1986), Ecology, Beauty, Profits: Trade in Lichen-based Dyestuffs through Western History. Journal of the Society of Dyers and Colourists, 102: 221-227. https://doi.org/10.1111/j.1478-4408.1986.tb01073.x

Persson O. (1997). The Chanterelle Book. Berkeley, California: Ten Speed Press. ISBN 978-0-89815-947-9
Pilz, D. & Molina, R. (1996) Managing forest ecosystems to conserve fungus diversity and sustain wild mushroom harvests. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Pilz, D. & Molina, R. (2002) Commercial harvests of edible mushrooms from the forests of the Pacific Northwest United States: issues, management, and monitoring for sustainability. Forest Ecology and Management. 155 (1), 3-16. 10.1016/S0378-1127(01)00543-6.

Pilz, D., Norvell, L., Danell, E. & Molina, R. (2003) USDA-FS PNW Research Station —Ecology and Management of Commercially Harvested Chanterelle Mushrooms.

Pilz, David. 2004. Chaga and other fungal resources: assessment of sustainable commercial harvesting in Khabarovsk and Primorsky Krais, Russia. Report prepared for Winrock International, Morrilton, Arkansas and the FOREST Project, Khabarovsk, Russia. April 30, 2004. 54 p

Pilz, D., Smith, J., Amaranthus, M., Alexander, S., Molina, R. & Luoma, D. (1999) Mushrooms and Timber: Managing Commercial Harvesting in the Oregon Cascades. Journal of Forestry. 97 4-11.

Pohl, C., Schmidt, B., Nunez Guitar, T., Klemm, S., Gusovius, H. J., Platzk, S., Kruggel-Emden, H., Klunker, A., Völlmecke, C., Fleck, C., & Meyer, V. (2022). Establishment of the basidiomycete Fomes fomentarius for the production of composite materials. Fungal biology and biotechnology, 9(1), 4. https://doi.org/10.1186/s40694-022-00133-y

Porsild, A.E. (1954). Edible Plants of the Arctic. *E.A Plant Sciences.* Pp 23-25. Available online at https://collections.dartmouth.edu/teitexts/arctica/diplomatic/EA06-15-diplomatic.html [Accessed 19.08.24].

Powell, M.J. (2017). Blastocladiomycota. In: Archibald, J., Simpson, A., Slamovits, C. (eds) Handbook of the Protists. Springer, Cham. https://doi.org/10.1007/978-3-319-28149-0_17

Ramel, G. (2015). "What is a Lichen?". Earthlife Web. Archived from the original on 19 January 2015.

Rather, L., Jameel, S., Ali, S., Bhat, K., & Yusuf, M. (2018). Lichen Derived Natural Colorants: History, Extraction, and Applications. *Handbook of Renewable Materials for Coloration and Finishing*, 103–114. https://doi.org/10.1002/9781119407850.ch6

Raut, J. K., Upadhyaya, J., Raghavan, V., Adhikari, M., Bhusal, S., Sainju, P., Gurmachhan, C., Giri, A., Bhatt, L. & Ranjan, L. (2019) Trade and Conservation of Morel Mushrooms in Nepal. International Journal of Natural Resource Ecology and Management. 4 183-187. 10.11648/j.ijnrem.20190406.14.

Reinoso, B., Rodriguez Gonzalez, I., & Domínguez, H. (2021). Towards greener approaches in the extraction of bioactives from lichens. *Reviews in Environmental Science and Bio/Technology*, *20*. https://doi.org/10.1007/s11157-021-09595-9

Rezaeian, S., & Pourianfar, H. R. (2016). Antimicrobial properties of the button mushroom, Agaricus bisporus: A mini-review. *International Journal of Advanced Research*, *4*(1), 426-429.

Richardson, D.H.S. (1988). Medicinal and Other Economic Aspects of Lichens in *Handbook of Lichenology.* CRC Press. ISBN: 9780429291869.

Rinaldi, A.C., Comandini, O., & Kuyper, T.W. (2008). "Ectomycorrhizal fungal diversity: separating the wheat from the chaff" (PDF). Fungal Diversity. 33: 1–45.

Rochet, J., Moreau, P.A., Manzi, S., & Gardes, M. (2011). "Comparative phylogenies and host specialization in the alder ectomycorrhizal fungi Alnicola, Alpova and Lactarius (Basidiomycota) in Europe". BMC Evolutionary Biology. 11: 40. doi:10.1186/1471-2148-11-40

Román, M. & Boa, E. (2006) The marketing of Lactarius deliciosus in Northern Spain. Economic Botany. 60 284-290. 10.1663/0013-0001(2006)60.

Rosa-Gruszecka, A., Gange, A. C., Harvey, D. J., Jaworski, T., Hilszczański, J., Plewa, R., Konwerski, S., & Hilszczańska, D. (2017). Insect-truffle interactions – potential threats to emerging industries? *Fungal Ecology*, *25*, 59–63. https://doi.org/10.1016/j.funeco.2016.10.004

Rowe, R. F. (1997) The commercial harvesting of wild edible mushrooms in the pacific northwest region of the United States. Mycologist. 11 (1), 10-15. 10.1016/S0269-915X(97)80060-2.

Rzymski, P., Mleczek, M., Niedzielski, P., Siwulski, M. & Gąsecka, M. (2017a) Cultivation of Agaricus bisporus enriched with selenium, zinc and copper. Journal of the Science of Food and Agriculture. 97 (3), 923-928. 10.1002/jsfa.7816.

Royal Botanic Gardens Edinburgh. (2018). Pages from the William Lauder Lindsay lichen dye collection out for a visit from @ScottishCrannog. The pages include fabrics coloured with lichen dyes and fine drawings. The backs have notes including recipes. Available at https://x.com/RBGE_Herbarium/status/1055422573696163842/photo/3 [Accessed 02/09/2024].

Rzymski, P., Mleczek, M., Siwulski, M., Jasińska, A., Budka, A., Niedzielski, P., Kalač, P., Gąsecka, M. & Budzyńska, S. (2017b) Multielemental analysis of fruit bodies of three cultivated commercial Agaricus species. Journal of Food Composition and Analysis. 59 170-178. 10.1016/j.jfca.2017.02.011.

Saito, H. & Mitsumata, G. (2008) Bidding Customs and Habitat Improvement for Matsutake (Tricholoma matsutake) in Japan. Economic Botany. 62 (3), 257-268. 10.1007/s12231-008-9034-7.

Sarmah, P. (2022). Chapter 10—Cyanolichens: An evolutionary perspective. In P. K. Singh, M. F. Fillat, V. Sitther, & A. Kumar (Eds.), *Expanding Horizon of Cyanobacterial Biology* (pp. 209–218). Academic Press. https://doi.org/10.1016/B978-0-323-91202-0.00001-4

Schwarze, Francis W. M. R.; Engels, Julia; Mattheck, Claus (2000). Fungal Strategies of Wood Decay in Trees. Springer. ISBN 978-3-540-67205-0.

Shah, N.C. (2014) Lichens of commercial importance in India. Scitech J 01:32–36

Shalchian-Tabrizi, K., Minge, M. A., Espelund, M., Orr, R., Ruden, T., Jakobsen, K. S., & Cavalier-Smith, T. (2008). Multigene Phylogeny of Choanozoa and the Origin of Animals. *PLOS ONE*, *3*(5), e2098. https://doi.org/10.1371/journal.pone.0002098

Sharma, S. (2003) Trade of Cordyceps sinensis from high altitudes of the Indian Himalaya: Conservation and biotechnological priorities. Current Science-Bangalore-. 86 1614-1618.

Sharnoff, S. & Sharnoff, S. (2014). "Lichen Biology and the Environment" Archived 17 October 2015.

Shevchuk, Y., Kuypers, K., & Janssens, G. E. (2023). Fungi as a source of bioactive molecules for the development of longevity medicines. *Ageing Research Reviews*, *87*, 101929. https://doi.org/https://doi.org/10.1016/j.arr.2023.101929

Shrestha, B., Zhang, W., Zhang, Y. & Liu, X. (2012) The medicinal fungus Cordyceps militaris: research and development. Mycological Progress. 11 (3), 599-614. 10.1007/s11557-012-0825-y.

Shukla, P., Upreti, D.K. (2015). Lichen Dyes: Current Scenario and Future Prospects. In: Upreti, D., Divakar, P., Shukla, V., Bajpai, R. (eds) Recent Advances in Lichenology. Springer, New Delhi. https://doi.org/10.1007/978-81-322-2235-4_12

Siegel, N. (2021a). Cantharellus cascadensis. The IUCN 2021: e.T195922608A195927578. https://dx.doi.org/10.2305/IUCN.UK.2021-2.RLTS.T195922608A195927578.en. Accessed on 15 September 2023.

Siegel, N. (2021b). Cantharellus formosus. The IUCN 2021: e.T195922677A195927703. https://dx.doi.org/10.2305/IUCN.UK.2021-2.RLTS.T195922677A195927703.en. Accessed on 15 September 2023.

Siegel, N. (2021c). Cantharellus roseocanus. The IUCN 2021: e.T195922611A195927637. https://dx.doi.org/10.2305/IUCN.UK.2021-2.RLTS.T195922611A195927637.en. Accessed on 15 September 2023.

Siegel, N. (2021d). Cantharellus subalbidus. The IUCN 2021: e.T195922624A195926181. https://dx.doi.org/10.2305/IUCN.UK.2021-2.RLTS.T195922624A195926181.en. Accessed on 15 September 2023.

Sinha, K. K., Choudhary, A. K., & Kumari, P. (2016). *Chapter 15 - Entomopathogenic Fungi* (B. T.-E. P. M. for F. S. Omkar (ed.); pp. 475–505). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-803265-7.00015-4

Sinigla, M., Lokos, L., Varga, N., & Farkas, E. (2015). Distribution of the legally protected lichen species Cetraria islandica in Hungary. *Studia Botanica Hungarica*, *46*, 91–100. https://doi.org/10.17110/StudBot.2015.46.1.91

Sitta, N. & Floriani, M. (2008) Nationalization and Globalization Trends in the Wild Mushroom Commerce of Italy with Emphasis on Porcini (Boletus edulis and Allied Species). Economic Botany. 62 307-322. 10.1007/s12231-008-9037-4.

Sitta, N. & Davoli, P. (2012) Edible Ectomycorrhizal Mushrooms: International Markets and Regulations. In: Zambonelli, A. & Bonito, G. M. (eds.). Edible Ectomycorrhizal Mushrooms: Current Knowledge and Future Prospects. Berlin, Heidelberg, Springer Berlin Heidelberg. pp. 355-380.

Skirina, I.F. (2020). Lichens of Kedrovaya Pad' Nature Reserve included in the Red Data Books of Russian Federation and Primorye Territory. *Biota and Environment of Natural Areas.* **1**: 62-68.

Sliva, D. (2003) Ganoderma lucidum (Reishi) in cancer treatment. Integrative Cancer Therapies. 2 (4), 358-364. 10.1177/1534735403259066.

Sonnenberg, A., Baars, J. J. P., Gao, W. & Visser, R. (2017) Developments in breeding of Agaricus bisporus var. bisporus: progress made and technical and legal hurdles to take. Applied Microbiology and Biotechnology. 101 10.1007/s00253-017-8102-2.

Speer, B.R. & Waggoner, B. (1997). "Lichens: Life History & Ecology". University of California Museum of Paleontology. Archived from the original on 2 May 2015.

Spribille, T., Tuovinen, V., Resl, P., Vanderpool, D., Wolinski, H., Aime, M.C., Schneider, K., Stabentheiner, E., Toome-Heller, M., Thor, G., Mayrhofer, H., Johannesson, H. & McCutcheon, J.P. (2016) Basidiomycete yeasts in the cortex of ascomycete macrolichens. Science 353 (6298): 488–492.

Stobbe, U., Egli, S., Tegel, W., Peter, M., Sproll, L. & Büntgen, U. (2013) Potential and limitations of Burgundy truffle cultivation. Applied Microbiology and Biotechnology. 97 (12), 5215-5224. 10.1007/s00253-013-4956-0.

Svanberg, I., & Lindh, H. (2019). Mushroom hunting and consumption in twenty-first century post-industrial Sweden. Journal of ethnobiology and ethnomedicine, 15(1), 42. https://doi.org/10.1186/s13002-019-0318-z

Svanberg, I., & Løvaas, M. (2023). *Previously neglected – now increasingly popular The recent acceptance of funnel chanterelle, Craterellus tubaeformis (Fr.) Quél., as food in contemporary Scandinavia (Norway, Sweden).* https://doi.org/10.21203/rs.3.rs-3173005/v1

Sugawara, R., Maekawa, N., Sotome, K., Nakagiri, A., & Endo, N. (2022). Systematic revision of Hydnum species in Japan. Mycologia, 114(2), 413–452. https://doi.org/10.1080/00275514.2021.2024407

Sugawara, R., Sotome, K., Maekawa, N., Nakagiri, A., & Endo, N. (2021). Mycorrhizal synthesis, morpho-anatomical characterization of mycorrhizae, and evaluation of mycorrhiza-forming ability of Hydnum albidum–like species using monokaryotic and dikaryotic cultures. *Mycorrhiza*, *31*(3), 349–359. https://doi.org/10.1007/s00572-021-01024-7

Sugawara, R., Yamada, A., Kawai, M., Sotome, K., Maekawa, N., Nakagiri, A., & Endo, N. (2019). Establishment of monokaryotic and dikaryotic isolates of Hedgehog mushrooms (Hydnum repandum and related species) from basidiospores. *Mycoscience*, *60*(3), 201–209. https://doi.org/https://doi.org/10.1016/j.myc.2019.02.007

Sun, Y., Li, J., Zhang, Y., Tu, Y., Huang, C., Tao, J., Yang, M., & Yang, L. (2018). The Polysaccharide Extracted from Umbilicaria esculenta Inhibits Proliferation of Melanoma Cells through ROS-Activated Mitochondrial Apoptosis Pathway. *Biological and Pharmaceutical Bulletin*, *41*(1), 57–64. https://doi.org/10.1248/bpb.b17-00562

Sung, G. H., Hywel-Jones, N. L., Sung, J. M., Luangsa-Ard, J. J., Shrestha, B., & Spatafora, J. W. (2007). Phylogenetic classification of Cordyceps and the clavicipitaceous fungi. Studies in mycology, 57, 5–59. https://doi.org/10.3114/sim.2007.57.01

Suzuki, S. U., & Sasaki, A. (2019). Ecological and Evolutionary Stabilities of Biotrophism, Necrotrophism, and Saprotrophism. The American Naturalist, 194(1), 90–103. https://doi.org/10.1086/703485

Tan, Q., You, L., Hao, C., Wang, J., & Liu, Y. (2024). Effects of four bolete species on ectomycorrhizae formation and development in Pinus thunbergii and Quercus acutissima. BMC Ecology and Evolution, 24(1), 54. https://doi.org/10.1186/s12862-024-02239-w

Taylor, T. N., Taylor, E. L., & Krings, M. (2009). *3 - Fungi, Bacteria, and Lichens* (T. N. Taylor, E. L. Taylor, & M. B. T.-P. (Second E. Krings (eds.); pp. 71–119). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-373972-8.00003-6

Tedersoo, L., May, T.W., & Smith, M.E. (2010). "Ectomycorrhizal lifestyle in fungi: global diversity, distribution, and evolution of phylogenetic lineages". Mycorrhiza. 20 (4): 217–263.

The Danish Morel Project. (2021). Available online at https://thedanishmorelproject.com/the-morel-project/ [Accessed 02/09/2024].

Thomas, P., Elkhateeb, W. & Daba, G. (2020) Chaga (Inonotus obliquus): a medical marvel but a conservation dilemma? Sydowia -Horn-. 72 123-130. 10.12905/0380.sydowia72-2020-0123.

Tomšovský, M., Kaeochulsri, S., Kudláček, T., & Dálya, L. B. (2023). Ecological, morphological and phylogenetic survey of Fomes fomentarius and F. inzengae (Agaricomycetes, Polyporaceae) co-occurring in the same geographic area in Central Europe. *Mycological Progress*, *22*(12), 79. https://doi.org/10.1007/s11557-023-01928-y

Trudell, S. (2012). The Genus Tricholoma in North America. *FUNGI* **5.5** pp 23-31. Available online at https://www.fungimag.com/winter-2013-

articles/TricholomaFixed013113LR.pdf [Accessed 06/08/2024].

Tuli, H. S., Sandhu, S. S., & Sharma, A. K. (2014). Pharmacological and therapeutic potential of Cordyceps with special reference to Cordycepin. 3 Biotech, 4(1), 1–12. https://doi.org/10.1007/s13205-013-0121-9

United Nations Statistics Division, UN COMTRADE. International Merchandise Trade Statistics. Available online at http://comtrade.un.org/ [Accessed 06/08/2024].

Upreti, D. K., Divakar, P. K., & Nayaka, S. (2005). Commercial and Ethnic Use of Lichens in India. *Economic Botany*, *59*(3), 269–273.

Uredba o zavarovanih prosto živečih vrstah gliv. (2011). Decree on the Protection of Wild Fungi. Available at http://nwfp-policies.efi.int/wiki/Decree_on_the_protection_of_wild_fungi,_2011_(Slovenia) [Accessed 07/05/2024].

Van, C.A, & Son, T.N. (2024). The Mushroom Albatrellus confluens: A Minireview on Phytochemistry, Biosynthesis, Synthesis and Pharmacological Activities. Current Topics in Medicinal Chemistry. 24. 487-502. 10.2174/0115680266291757240124093756.

Velmala, S., Myllys, L., Halonen, P., Goward, T. & Ahti, T. (2009) Molecular data show that Bryoria fremontii and B. tortuosa (Parmeliaceae) are conspecific. The Lichenologist 41 (3): 231–242.

Verbeken, A., & Buyck, B. (2002). Diversity and ecology of tropical ectomycorrhizal fungi in Africa. In: Tropical Mycology: Macromycetes (eds. Watling R, Frankland JC, Ainsworth AM, Isaac S, Robinson CH.) (PDF). pp. 11–21. Archived from the original (PDF) on 2014-10-06

Vellinga, E.C., Wolfe, B.E., & Pringle, A. (2009). "Global patterns of ectomycorrhizal introductions". New Phytologist. 181 (4): 960–973. doi:10.1111/j.1469-8137.2008.02728.x

Volk, T. (2003). "Hericium americanum, the pom pon mushroom, a.k.a. Lion's mane, the bear's head tooth fungus, monkey head, or for this month, the icicle mushroom". Fungus of the Month for January 2003.

Waksman, S. A. & Nissen, W. (1932) On the Nutrition of the Cultivated Mushroom, Agaricus campestris, and the Chemical Changes Brought about by this Organism in the Manure Compost. American Journal of Botany. 19 (6), 514-537. 10.2307/2436074.

Wang, Y. & Chen, Y. (2014) Recent Advances in Cultivation of Edible Mycorrhizal Mushrooms. In: Anonymous pp. 375−397.
Wang, X., Yang, Z., Li, Y., Knudsen, H. & Liu, P. (2009) Russula griseocarnosa sp nov (Russulaceae, Russulales), a commercially important edible mushroom in tropical China: mycorrhiza, phylogenetic position, and taxonomy. Nova Hedwigia. 88 269-282. 10.1127/0029-5035/2009/0088-0269.

Wang, P., Zhang, Y., Mi, F., Tang, X., he, X., Cao, Y., Liu, C., Yang, D., Dong, J., Zhang, K. & Xu, J. (2015) Recent advances in population genetics of ectomycorrhizal mushrooms Russula spp. Mycology. 6 1-11. 10.1080/21501203.2015.1062810.

Watkinson, S. C. (2016). Chapter 7—Mutualistic Symbiosis Between Fungi and Autotrophs. In S. C. Watkinson, L. Boddy, & N. P. Money (Eds.), *The Fungi (Third Edition)* (pp. 205–243). Academic Press. https://doi.org/10.1016/B978-0-12-382034-1.00007-4

Wei, X., Deng, H., & Wei, J. (2020). Threatened Categories Assessment of Lichens in China. *Biodiv. Sci.* 28(1):54-65.

Wennig, R., Eyer, F., Schaper, A., Zilker, T., & Andresen-Streichert, H. (2020). Mushroom Poisoning. Deutsches Arzteblatt international, 117(42), 701–708. https://doi.org/10.3238/arztebl.2020.0701

Weston, C. J., & Whittaker, K. L. (2004). *SOIL BIOLOGY AND TREE GROWTH | Soil Biology* (J. B. T.-E. of F. S. Burley (ed.); pp. 1183–1189). Elsevier. https://doi.org/https://doi.org/10.1016/B0-12-145160-7/00248-9

Westrip, J.R.S. (2022). Cantharellus miomboensis. The IUCN 2022: e.T189959737A217823024. Accessed on 15 September 2023.

Whittaker, W. (1969) New Concepts of Kingdoms of Organisms. Science. 163 (3863), 150-160. 10.1126/science.163.3863.150.

Wijayawardene NN, Hyde KD, Al-Ani LK, Tedersoo L, Haelewaters D, Rajeshkumar KC, et al. (2020). "Outline of Fungi and fungus-like taxa" (PDF). Mycosphere. 11 (1): 1060–1456. doi:10.5943/mycosphere/11/1/8.

Willis, K. J. (ed.) (2018). State of the World's Fungi 2018. Report. Royal Botanic Gardens, Kew.

Wisitrassameewong, K., Karunarathna, S., Thongklang, N., Zhao, R., Callac, P., Serge, M., Férandon, C., Chukeatirote, E. & Hyde, K. (2012) Agaricus subrufescens: A review. Saudi Journal of Biological Sciences. 19 131-146. 10.1016/j.sjbs.2012.01.003.

Wolfe, B.E., Richard, F., Cross, H.B. and Pringle, A. (2010), Distribution and abundance of the introduced ectomycorrhizal fungus Amanita phalloides in North America. New Phytologist, 185: 803-816. https://doi.org/10.1111/j.1469-8137.2009.03097.x

Wrobleski, A., Ernst, S., Weber, T., & Delach, A. (2023) The impact of climate change on endangered plants and lichen. PLOS Clim 2(7): e0000225. https://doi.org/10.1371/journal.pclm.0000225

Wu, F., Yuan, Y., Malysheva, V., Du, P. & Dai, Y. (2014). Species clarification of the most important and cultivated Auricularia mushroom "Heimuer": evidence from morphological and molecular data Phytotaxa. 186 241. 10.11646/phytotaxa.186.5.1.

Xiao-Liang, W., & Yi-Jian, Y. (2011). "Host insect species of Ophiocordyceps sinensis: a review". ZooKeys (127): 12743–59. doi:10.3897/zookeys.127.802

Xing, X. K., & Guo, S. X. (2008). "The Structure and Histochemistry of Sclerotia of Ophiocordyceps sinensis". Mycologia. 100 (4): 616–625. doi:10.3852/07-007R2

Xu, Y., Tang, J., Wang, Y., He, X., Tan, H., Yu, Y., Chen, Y. & Peng, W. (2022) Large-scale commercial cultivation of morels: current state and perspectives. Applied Microbiology and Biotechnology. 106 1-12. 10.1007/s00253-022-12012-y.

Yahr, R., Allen, J., Lymbery, C., Batallas-Molina, R., Bungartz, F., Dal Forno, M., Howe, N., Lendemer, J., McMullin, T., Mertens, A., Paquette, H., Petix, M., Reese Næsborg, R., Roberts, F., Sharrett, S. & Villella, J. (2021). Parmelia saxatilis. The IUCN. e.T194660573A194678129. https://dx.doi.org/10.2305/IUCN.UK.2021-2.RLTS.T194660573A194678129.en

Yang, M., Devkota, S., Wang, L., & Scheidegger, C. (2021). Ethnolichenology-The Use of Lichens in the Himalayas and Southwestern Parts of China. *Diversity*, *13*, 330. https://doi.org/10.3390/d13070330

Yang, Z.-L. 2020. Ophiocordyceps sinensis (amended version of 2020 assessment). The IUCN 2020: e.T58514773A179197748. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T58514773A179197748.en. Accessed on 15 September 2023.

Yuan, Y., Wu, F., Si, J., Zhao, Y. & Dai, Y. (2019) Whole genome sequence of Auricularia heimuer (Basidiomycota, Fungi), the third most important cultivated mushroom worldwide. Genomics. 111 (1), 50-58. 10.1016/j.ygeno.2017.12.013.

Yun, W., Hall, I. R. & Evans, L. A. (1997) Ectomycorrhizal Fungi with Edible Fruiting Bodies 1. Tricholoma matsutake and Related Fungi. Economic Botany. 51 (3), 311-327. http://www.jstor.org/stable/4255972.

Yun, W. & Hall, I. (2004) Edible Ectomycorrhizal Mushrooms: Challenges and Achievements. Canadian Journal of Botany-Revue Canadienne De Botanique - CAN J BOT. 82 1063-1073. 10.1139/b04-051.

Zabel, R. A., & Morrell, J. J. (2020). *Chapter Three - The characteristics and classification of fungi and bacteria* (R. A. Zabel & J. J. B. T.-W. M. (Second E. Morrell (eds.); pp. 55–98). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-819465-2.00003-6

Zhang, Y., Lin, W., Buyck, B., Liang, Z., Su, M., Chen, Z., Zhang, P., Jiang, S., An, D. & Zeng, N. (2022) Morphological and Phylogenetic Evidences Reveal Four New Species of Cantharellus Subgenus Cantharellus (Hydnaceae, Cantharellales) From China. Frontiers in Microbiology. 13 900329. 10.3389/fmicb.2022.900329.

Zhang, Y., Sun, S., Luo, D., Mao, P., Rosazlina, R., Martin, F. & Xu, L. (2023) Decline in Morel Production upon Continuous Cropping Is Related to Changes in Soil Mycobiome. Journal of Fungi (Basel, Switzerland). 9 (4), 492. doi: 10.3390/jof9040492. 10.3390/jof9040492.

Zhang, M., Sun, X., Miao, Y., Li, M. & Huang, L. (2022a) Cordyceps cicadae and Cordyceps gunnii have closer species correlation with Cordyceps sinensis: from the perspective of metabonomic and MaxEnt models. Scientific Reports. 12 (1), 20469. 10.1038/s41598-022-24309-z.

Zhang, M., Wang, C., Gan, M., Li, Y., Shao, S., Qin, W., Deng, W. & Li, T. (2022b) Diversity of Cantharellus (Cantharellales, Basidiomycota) in China with Description of Some New Species and New Records. Journal of Fungi (Basel, Switzerland). 8 (5), 483. doi: 10.3390/jof8050483. 10.3390/jof8050483.

Zhang, F., Yang, X., Wang, D., Lei, S., Guo, L., Liu, W. & Song, J. (2020) A simple and effective method to discern the true commercial Chinese cordyceps from counterfeits. Scientific Reports. 10 (1), 2974. 10.1038/s41598-020-59900-9.

Zhang, Y., Zeng, Y., Men, Y., Zhang, J., Liu, H., & Sun, Y. (2018). Structural characterization and immunomodulatory activity of exopolysaccharides from submerged culture of Auricularia auricula-judae. International journal of biological macromolecules, 115, 978-984.

Zhang, P., Tang, L. P., Cai, Q., & Xu, J. P. (2015). A review on the diversity, phylogeography and population genetics of Amanita mushrooms. Mycology, 6(2), 86–93. https://doi.org/10.1080/21501203.2015.1042536

Zhao, Y., Wang, M., & Xu, B. (2021). A comprehensive review on secondary metabolites and health-promoting effects of edible lichen. *Journal of Functional Foods*, *80*, 104283. https://doi.org/https://doi.org/10.1016/j.jff.2020.104283

Zhao, X., Wei, Y., Gong, X., Xu, H. & Xin, G. (2020) Evaluation of umami taste components of mushroom (Suillus granulatus) of different grades prepared by different drying methods. Food Science and Human Wellness. 9 (2), 192-198. 10.1016/j.fshw.2020.03.003.

Zheng, H. & Liu, P. (2008) Additions to our knowledge of the genus Albatrellus (Basidiomycota) in China. Fungal Diversity. 32 .

Zhou, H., Guo., M.-J., Zhuo, L., Yan, H.-F., Sui, X.-N., Gao, Y., & Hou, C.-L. (2023). Diversity and Taxonomy of the genus Amanita (Amanitaceae, Agaricales) in the Yanshan Mountains, Northern China. Frontiers in Plant Sciences:14 https://doi.org/10.3389/fpls.2023.1226794

Zhou, X., Su, K. & Zhang, Y. (2011) Applied modern biotechnology for cultivation of Ganoderma and development of their products. Applied Microbiology and Biotechnology. 93 941-63. 10.1007/s00253-011-3780-7.

Zhu, J.S., Halpern, G.M., & Jones, K. (1998). "The scientific rediscovery of an ancient Chinese herbal medicine: Cordyceps sinensis: part I". J Altern Complement Med. 4 (3): 289–303. doi:10.1089/acm.1998.4.3-289