**Macrofungi as ecosystem resources: Conservation versus exploitation**

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**DOI:** 10.1080/11263504.2012.753133

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# Abstract

Fungi are organisms of significant importance not only for the crucial roles they undertake in nature but also for many human activities that are strictly dependent on them. Indeed, fungi possess fundamental positions in ecosystems functioning including nutrient cycles and wood decomposition. As concerns human-related activities, edible and non-edible mushrooms are also involved and/or exploited in forestry, pharmaceutical industry and food production; hence, nowadays they represent a major economic source worldwide. In order to maintain and improve their strategic importance, several conservation strategies, such as habitat preservation, are needed. This article reports several contributions inherent to the relationships between wood-decaying fungi, edible and non-edible mushrooms and their potential exploitation as non-timber forest products and genetic resources.

### Keywords

- Mycodiversity,
- wood-decay fungi,
- mushroom,
- truffle,
- exploitation

# Introduction

Fungi represent one of the most rich and diverse group of organisms in the world, and they are valuable not only for their vital roles in ecosystem functions but also for their influence on humans and human-related activities (Mueller et al. 2004). The existence of entire ecosystems would be compromised without the presence of fungi. However, despite their functional importance, they are often overlooked and left out of conservation initiatives.

Among different natural environments, also considering their relationships between climate and vegetation (Blasi et al. 1999), forests host the highest richness of macrofungi (i.e. fungi producing sporomata larger than 1 mm; Arnolds 1981). In the last century, their growth conditions were dramatically influenced by human activities. Negative effects of clear-cutting and timber harvesting caused the decrease or shrinkage of specific habitats (e.g. old-growth forests) and led to the lack of coarse dead wood, which constitutes the essential element of fungal growth (Dahlberg et al. 2010). Nevertheless, the quantity and quality of dead wood are significantly decreasing as a consequence of the disappearance of old-growth forests, which are generally rich in dead wood. Since it is estimated that about 50% of forest macrofungi are wood decaying (Senn-Irlet 2007), the existence of these organisms is dependent on a continuous supply of dead wood because of their tight involvement in organic matter recycling (Küffer & Senn-Irlet 2005), notably in the primary decomposition of coarse wood debris all the way until the complete disintegration of wood residues. Hence, they govern subsequent food-webs and play important roles in several other nutrient cycles. Microbial decomposition of foliar/root/woody plant litter is a basic process in ecosystems functioning, primarily bacause of the release of nutrients to plants and also because of the formation of stable humus serving as nutrient storage and reservoir. It has also been shown that dead wood (found in advanced stages of decay on the ground) is important for the establishment of mycorrhizal associations with plant seedlings, and that woody debris acts as a moisture sink valuable for the maintenance of mycorrhizal fungi associations in seasonally dry forests (Huhndorf et al. 2004).

Wild macrofungi constitute a natural resource widely acknowledged for their nutritional and economic value and their medicinal properties in both developing and developed countries. Studies published so far bring clear evidence of the economic significance of wild mushrooms, especially for the stakeholders at the base of the market chain (De Roman 2010), and they justifiably are among the most important non-timber forest products. More than 3000 species of wild edible mushrooms are consumed around the world possessing an estimated total value of $2 billion (Garibay-Orijel et al. 2009).

However, wild edible mushrooms could easily be considered as underutilized genetic resources since their potential market is still far from being fully developed. Some of the pertinent criteria reported by Padulosi et al. (2002) in the case of vegetable crops can be applied to edible mushrooms of noteworthy organoleptic properties and commercial value. For example, *Amanita caesarea* (Scop.) Pers., *Cantharellus cibarius* Fr. and *Boletus edulis* Bull. are considered as prized edible mushrooms (hence they meet the respective market's demands) and they are rather easily identified among other related poisonous species (hence, they are suitable for picking by non-expert members of rural communities). Cultivated *Pleurotus* and *Tuber* species are relatively easy to establish as alternative crops, with low capital and labour inputs, have fast growth (*Pleurotus* spp.), produce high yields of quality products and their cultivation is compatible with other types of land use. Macrofungi also contribute to the diversification and improvement of human diet (La Guardia et al. 2005; Palazzolo et al. 2012), whereas most importantly they have the potential to act as sources of additional income for farmers by exploiting agricultural by-products of low economic value (Zervakis & Venturella 2002).

Because of macrofungi's significant ecological and economic importance, devising strategies for their conservation are urgently needed. The loss of suitable habitats is considered by many mycologists to be the major threat for fungal conservation (Watling 2005; Minter 2011). The negative effects of various forest activities, such as (irrational) mushroom harvesting, (uncontrolled) trade of non-timber forest products and modern (but not appropriate) forestry practices, should be mitigated in order to protect biodiversity. In other words, preserving forests that are particularly rich in biodiversity means protecting the biodiversity within forests as well.

This article aimed at highlighting several aspects related to the role and the inherent relationships existing among wood-decaying fungi, edible and non-edible mushrooms inclusive of. both hypogeous and epigeous species. Moreover, some concerns about the possible exploitation of mushroom fungi as non-timber forest products are considered and discussed.

# Linking biodiversity of forest wood-decaying and epigeous (edible and non-edible) fungi

## Fungal species richness in Parco Nazionale del Cilento e Vallo di Diano (PNCVD, southern Italy) forest stands

Saproxylic and other epigeous macrofungi were investigated in the frame of an integrated research project carried out since 2008 in broad-leaved forest stands of the PNCVD, which were previously subjected to various management practices (Marchetti et al. 2010; Persiani et al. 2010; Saitta et al. 2011). In this research context, biodiversity of forest saproxylic and epigeous fungi (edible and non-edible) was presumably linked. To test such a hypothesis, presence/absence of data for surveyed fungal species was used since species richness (SR) (defined as the total number of species present) represents a common approach for assessing the biodiversity in a framework of biological conservation.

The surveys of saproxylic and other epigeous macrofungi were contextually carried out in the PNCVD in spring and autumn, during the expected peaks of fruiting, over a 2-year survey period (2010–2011), in 16 plots selected for this investigation. A total number of 380 species were recorded: 167 species of saproxylic and 213 species of epigeous macrofungi, 31 belonging to *Ascomycota* and 349 to *Basidiomycota*. The highest value of saproxylic and other epigeous macrofungi recorded from the same plot (an old-growth beech forest with *Abies alba* Mill. and *Taxus baccata* L.) was 72 and 59 species, respectively.

For each plot, the diversity of edible, saproxylic and epigeous macrofungi has been considered. As concerns the total SR of saproxylic macrofungi, the following edible taxa were recorded: *Armillaria mellea* (Vahl) P. Kumm., *Auricularia auricula-judae* (Bull.) Quél., *Lycoperdon pyriforme* Schaeff., *Meripilus giganteus* (Pers.) P. Karst., *Mucidula mucida* (Schrad.) Pat., *Pleurotus dryinus* (Pers.) P. Kumm., *Pleurotus ostreatus* (Jacq.) P. Kumm., *Pluteus cervinus* (Schaeff.) P. Kumm., *Pluteus ephebeus* (Fr.) Gillet, *Pluteus phlebophorus* (Ditmar) P. Kumm., *Pluteus thomsonii* (Berk. and Broome) Dennis, *Polyporus squamosus* (Huds.) Fr. and *Hymenopellis radicata* (Relhan) R.H. Petersen.

Referring to the total SR of epigeous macrofungi, the most frequent taxa were (in decreasing order): *C. cibarius*, *Infundibulicybe costata* (Kühner and Romagn.) Harmaja, *Clitocybe odora* (Bull.) P. Kumm., *Lycoperdon perlatum* Pers., *Macrolepiota procera* (Scop.) Singer, *Clitopilus prunulus* (Scop.) P. Kumm., *Lycoperdon echinatum* Pers., *Clitocybe gibba* (Pers.) Harmaja, *Hydnum rufescens* Pers. and *Russula cyanoxantha* (Schaeff.) Fr.

Worth mentioning are some *B. edulis* records; however, these were recorded low frequency because of intense harvesting from local mushrooms hunters (they were also harvested for trade purposes).

For each plot, Spearman's correlation coefficients were calculated by SPSS (2009) between: (i) plot attributes (vegetation type, old-growth degree), (ii) saproxylic and epigeous macrofungi SR, (iii) the SR of saproxylic and epigeous macrofungi with respect to edible and non-edible, respectively and (iv) the total SR of edible and non-edible macrofungi.

The correlation matrix for the fungal SR data (Table I) shows that significant SR relationships occur between saproxylic and epigeous macrofungi ($p < 0.05$), between saproxylic and epigeous edible

($p < 0.05$) and between both saproxylic and saproxylic non-edible and total edibles ($p < 0.01$). Referring to this data set, there are no significant correlations between SR data and plot attributes. Other statistically significant species relationships were observed between some SR data, which however cannot be taken into account since they resulted from autocorrelation between dependent data.

**Table 1 Spearman's correlation coefficients for SR data, and between species richness data and plot attributes data.**

| | **Plot attributes** | | | | **Fungal species richness (SR)** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Vegetation type** | **Old-growth degree** | **SR epigeous** | **SR saproxylic** | **SR epigeous edible** | **SR epigeous no-edible** | **SR saproxylic edible** | **SR saproxylic no-edible** | **SR total edible** | **SR total no-edible** |
| Vegetation type | 1 | 0.121 | − 0.058 | 0.175 | − 0.16 | − 0.09 | 0.428 | 0.099 | − 0.051 | 0.01 |
| Old-growth degree | | 1 | − 80.005 | − 0.099 | − 0.095 | 0.061 | 0.012 | − 0.137 | − 0.128 | − 0.095 |
| SR epigeous | | | 1 | 0.510* | 0.841** | 0.970** | 0.558* | 0.364 | 0.801** | 0.742** |
| SR saproxylic | | | | 1 | 0.586* | 0.513* | 0.795** | 0.960** | 0.671** | 0.897** |
| SR epigeous edible | | | | | 1 | 0.745** | 0.590* | 0.507* | 0.973** | 0.689** |
| SR epigeous no-edible | | | | | | 1 | 0.523* | 0.38 | 0.703** | 0.778** |
| SR saproxylic edible | | | | | | | 1 | 0.654** | 0.731** | 0.670** |
| SR saproxylic no-edible | | | | | | | | 1 | 0.567* | 0.834** |
| SR total edible | | | | | | | | | 1 | 0.711** |
| SR total no-edible | | | | | | | | | | 1 |

The results of this study highlight the importance of edible and non-edible saproxylic fungi in predicting SR values for epigeous edible and non-edible macrofungi, thereby confirming the findings reported in other studies (e.g. Boddy 2001; Berg & McClaugherty 2003; Rajala et al. 2011) about woody debris decomposition and fungal SR.

Apart from weather conditions, fruiting phenology and productivity of wild macrofungi result from a sequence of processes that are possibly linked with regulatory signals and resource availability. In order to deepen the knowledge of such complex systems, it is also important to take into account the relationships between biodiversity of saproxylic, saprotrophic and ectomycorrhizal epigeous, and edible and non-edible macrofungi as a valid tool to improve forest management practices aiming at protecting these natural resources and their functional role across ecosystems.

In Europe many specific threats were identified for macrofungi, which include among others, the decline and shrinkage of old-growth forests and the decline in the viability of coarse dead wood (the change in the use of land is the major cause of the decline of macrofungal diversity, e.g. Josefsson et al. 2010). Furthermore, in several European countries, picking of edible fungi for commercial purposes has led to an increase in awareness about over-harvesting and possible damage to indigenous fungal resources. Harvesting of edible mushrooms (including those of many ectomycorrhizal fungi) may also have adverse long-term effects, such as a decrease in spores availability due to removal of immature sporomata, especially for species with fragmented and very small populations (Senn-Irlet 2007).

## Macrofungal in a site of community importance (SCI) of Umbria

The study was carried out in the forest of Collestrada (Umbria, central Italy), an area of approximately 136 ha (250–306 m a.s.l.), which is characterized by an exceptional wealth of flora, fauna and SR, and it was declared a SCI in 2008. Mycological surveys were conducted in 2011 by means of the tracking method, mainly throughout the most widespread local plant communities: (1) *Carpinus betulus* L. woodland (*Erythronio-Carpinion betuli*), (2) *Quercus cerris* L. woodland (*Lonicero xilostei-Quercetum cerridis*), (3) *Quercus farnetto* Ten. woodland (*Malo florentinae-Quercetum farnetto*), (4) *Quercus petraea* (Matt.) Liebl. woodland (*E. betuli*), (5) *Quercus ilex* L. woodland (*Rusco aculeati-Querceto ilicis*) and (6) plantations with *Pinus pinea* L. and/or *Pinus pinaster* Aiton.

The list of mycobiota includes 119 species of macrofungi belonging to 65 genera, and corresponds to 113 *Basidiomycota* and 6 *Ascomycota* species. According to Arnolds et al. (1995), these 119 species belong to the following trophic groups: 35% ectomycorrhizal fungi; 57% saprotrophs further divided into terrestrial (31%), litter (7%) and lignicolous saprotrophs (19%); 7% parasitic fungi and 1% fungi associated with bryophytes.

Edible species represent about 25% of the total fungal species. Among them, the most frequently noted were *A. caesarea* (Scop.) Pers., *Boletus aereus* Bull., *Boletus aestivalis* (Paulet) Fr., *Calocybe gambosa* (Fr.) Donk, *C. cibarius* (Fr.) Donk, *Craterellus cornucopioides* (L.) Pers., *Macrolepiota konradii* (Huijsman ex P.D. Orton) M.M. Moser, *Russula* spp. and *Tuber aestivum* Vittad. The analysis of the fungi recorded in Collestrada forest revealed the dominance of different species, the most frequently found were: *Entoloma sinuatum* (Bull.) P. Kumm associated with broad-leaved woods, *Craterellus lutescens* (Fr.) Fr., *Baeospora myosura* (Fr.) Singer associated with conifers. The number of fungal species recorded in acidophilic *Q. farnetto* woodland was greater than that recorded in all the other woodland types investigated, and certain species (e.g. *Amanita vaginata* (Bull.) Lam., *Inocybe geophylla* (Fr.) P. Kumm., *Lactarius piperatus* (L.) Pers. and *Russula maculata* (Quél.)) showed a notable preference for this environment.

Although this study covers only 1-year time-span, it represents a contribution towards better profiling the mycodiversity in Italy.

# Mushrooms as non-timber forest products

## Exploitation of epigeous macrofungi

Several cases of setting-up production lines based on the exploitation of wild edible fungi are currently detectable in the Mediterranean area with particular reference to Italy and Greece. These processes are based on the accurate identification of wild edible mushrooms with valuable organoleptic characters. The mycelium of the fungus, isolated in the laboratory, is used for the selection of different strains which are genetically well characterized; these are in turn used for spawn preparation and inoculation of cultivation substrates. These substrates, at the end of the standardized processes of pasteurization/sterilization and after inoculation, are supplied to the farmer for the production of edible mushrooms. Farmers are mainly represented by people who already work in the agricultural sector but who want to try alternative crops which will enable them to supplement their income. Indigenous mushroom species such as *Pleurotus eryngii* var. *eryngii*, *P*. *eryngii* var. *elaeoselinii*, *P*. *eryngii* var. *ferulae*, *P*. *eryngii* var. *thapsiae*, *P*. *nebrodenis*, *Agrocybe cylindracea* and *Hericium erinaceus* have already been tested in pilot and commercial-scale cultivation trials and they already constitute alternative crops in some rural communities of the two countries (Zervakis & Venturella 2002; Varese et al. 2011; Zervakis & Koutrotsios 2011). Moreover, many wild mushroom species are already examined as potent agents for wastes biodegradation. For example, pertinent research has demonstrated that wood-decomposing basidiomycetes, such as *Bjerkandera adusta*, *Abortiporus biennis*, *Dichomitus squalens*, *Ganoderma* spp., *Inonotus hispidus*, *Irpex lacteus*, *Lentinus tigrinus*, *Panellus stipticus*, *Phanerochaete chrysosporium*, *Pleurotus* spp. and *Trametes hirsuta*, are among the most powerful organisms to detoxify a wide range of pollutants, e.g. polycyclic aromatic hydrocarbons, chlorinated compounds, preservatives, textile-industry effluents, agro-industrial wastewater and herbicides (Aggelis et al. 2002; Wang et al. 2009; Anastasi et al. 2010; Da Silva Coelho et al. 2010; Inoue et al. 2010; Ntougias et al. 2012). These fungi selectively attack lignin and related compounds by producing phenol-targeting redox enzymes, namely peroxidases and laccases/phenoloxidases (Martinez et al. 2005; Baldrian 2006). It is of significant interest that all aforementioned species occur in the Mediterranean region and could be eventually used in pertinent biotechnological processes aiming at providing environmentally friendly and financially viable solutions in problems associated with local wastes disposal.

Further exploitation prospects of indigenous mushroom diversity are related to their use as biocontrol agents, e.g. *Pleurotus* and *Cordyceps* spp. against plant pests such as nematodes and insects, respectively (Chitwood 2002; Shah & Pell 2003), or as fungal inocula for the establishment of new tree stands and for reforestation initiatives linked or not with the cultivation of edible ectomycorrhizal mushroom species (Kropp & Langlois 1990; Bonet et al. 2006; Rincón et al. 2007). However, one of the most fast-growing pertinent commercial sectors is the one using mushrooms as source for the generation of medicinal compounds and dietary supplements. The consequent added value to the final product is significant since a wide range of health-beneficial substances were detected to occur in a large number of mushroom fungi. Indicative are the cases of *Pleurotus* species which are rich in dietary fibres, vitamin B, β-carotene, tocopherol and other valuable nutrients and antioxidants (Alarcón et al. 2003; Tsai et al. 2009), while they also contain a number of biologically active compounds, which were shown to modulate the immune system, inhibit tumour growth and inflammation, have hypoglycaemic and antithrombotic activities, lower blood lipid concentrations, prevent high blood pressure and atherosclerosis, and present antimicrobial and other activities (Gunde-Cimerman 1999; Wasser & Weiss 1999; Gregori et al. 2007). Similarly, *Ganoderma* spp. (especially *G. lucidum*) are among the most valuable mushroom fungi in the pharmaceutical industry since they contain several major substances (e.g. polysaccharides and triterpenoids) which demonstrate potent immuno-modulating effects, activation of macrophages, NK and T cells as well as enhanced anti-tumour activity in host-cells (Jong & Birmingham 1992;

Mizuno et al. 1995; Wasser & Weiss 1999; Gao et al. 2003). As more than 700 mushroom species were reported to possess medicinal properties (Chang 1999; Wasser 2002; Dai et al. 2009), it is obvious that this group of organisms represents a powerful arsenal of valuable pharmaceutical products or food supplements.

## Exploitation of important economical hypogeous macrofungi

Truffles are ecologically and economically important non-timber forest products. In nature, they contribute to carbon sequestration, improve tree growth and serve as a source of food for wildlife. Moreover, truffles are widely accepted as gastronomic treasures of high commercial value, and they are international best-sellers. Harvesting of truffles is an enjoyable hobby for many cultures, age groups and families, and it constitutes an activity that brings people to forests. Collected truffles contribute to the family diet or they supplement the family's income. Thus, truffles possess an important social, ecological and economic value (Benucci et al. 2012). Each truffle species demonstrates a particular ecology. The species with the highest market prices, *Tuber magnatum* Pico and *Tuber melanosporum* Vittad., grow in environments with quite different climatic, edaphic and botanical characteristics (Bencivenga et al. 1995; Granetti et al. 2005; Bragato 2010; Raglione et al. 2010). However, during the last decades, changes in woods management have led to a decline in natural truffle-grounds productivity. The development of an excessive layer of vegetation coverage as a result of abandoning agro-forestry management produced significant negative effects with respect to the amount of sunlight reaching the soil, competition between trees and water availability, all conferring at the deterioration of the microclimate suitable for *T. melanosporum* growth. Thus, *T. melanosporum* natural truffle-grounds began declining in production, and risks for its gradual disappearance or substitution by other truffle species or other fungi are apparent (Baciarelli Falini 2005).

Human interventions are required to keep suitable conditions for the growth of *T. melanosporum*. However, these interventions can be destructive when host trees are cut or when they lead to soil compaction. In the natural truffle-grounds of *T. magnatum*, hydraulic-forestry interventions, such as cutting of riparian vegetation or changes in the water level of rivers and streams, cause a progressive productivity decline and introduce risks of eliminating the valued truffle crops. Altering of natural conditions may lead to a *T. melanosporum*/*T. aestivum* substitution, but for *T. magnatum* the damage is significant, because the local economic value and biodiversity are completely lost while cultivation of this species is still in progress. For these reasons, any environmental management of potential truffle sites must consider multidisciplinary criteria based on knowledge of truffle ecology as a priority background to preserve and improve the natural production of these precious fungi. Other causes for the decline of natural truffle-grounds are climate changes and badly managed truffle collections on a wide scale. Thus, the loss of suitable habitats for natural truffle-grounds decreases the natural production of these fungi and reduces biodiversity. For improving this situation, truffles could be cultivated by using seedlings obtained from local biological material (both fungi and host plants), or else the natural conditions should be restored. In order to achieve these results, the knowledge of truffle ecology is a fundamental prerequisite as it may suggest the best practices to recover the non-productive sites. Several investigations aiming in determining such practices have been carried out in order to understand the effects of ectomycorrhizae levels and truffle production in natural and cultivated truffle sites as well (Murat et al. 2005; Baciarelli Falini et al. 2010; Iotti et al. 2010). Finally, some pertinent suggestions have been reported in books and handbooks as a result of many years of experience on truffles production (Zambonelli & Di Munno 1992; Bencivenga & Baciarelli Falini 2012); however, each case requires specific actions which have to be selected by specialized technicians.

# References


- **1.** Aggelis, G, Ehaliotis, C, Nerud, F, Stoychev, I, Lyberatos, G and Zervakis, GI. 2002. Evaluation of white-rot fungi for detoxification and decolorization of effluents from the green olives debiterring process. *Appl Microbiol Biotechnol*, 59: 353–360.
- **2.** Alarcón, J, Águila, S, Arancibia-Avila, P, Fuentes, O, Zamorano-Ponce, E and Hernández, M. 2003. Production and purification of statins from Pleurotus ostreatus (Basidiomycetes) strains. *Z Naturforsch*, 58: 62–64.
- **3.** Anastasi, A, Spina, F, Prigione, V, Tigini, V, Giansanti, P and Varese, GC. 2010. Scale-up of a bioprocess for textile wastewater treatment using Bjerkandera adusta. *Biores Technol*, 101: 3067–3075.
- **4.** Arnolds, E. 1981. Ecology and coenology of macrofungi in grasslands and moist heathlands in Drenthe, the Netherlands. Part 1. *Bibliotheca Mycol*, 83: 1–410.
- **5.** Arnolds, E, Kuyper, ThW and Noordeloos, EM. 1995. *Overzicht van de paddestoelen in Nederland*, 1–872. Wijster: Nederlandse Mycologische Vereniging.
- **6.** Baciarelli Falini L. 2005. Prime osservazioni sulla sostituzione delle micorrize di Tuber nelle tartufaie coltivate. Atti Seminario sullo Stato attuale della Tartuficoltura Italiana, Spoleto – Norcia (PG), 21–22/02/2004, Associazione “il Tartufo nel 2000” – Gruppo Micologico “Valle Spoletana” pp. 75–80
- **7.** Baciarelli Falini L, Bencivenga M, Donnini D, Di Massimo G. 2010. Risultati delle ricerche nelle tartufaie della Regione Umbria. Proceedings from the 3rd International Congress on Tuber, Spoleto, Italy, pp. 577–589, ISBN 9788890512209
- **8.** Baldrian, P. 2006. Fungal laccases – occurrence and properties. *FEMS Microbiol Rev*, 30: 215–242.
- **9.** Bencivenga M, Baciarelli Falini L. 2012. Manuale di Tartuficoltura. Esperienze di coltivazione dei Tartufi in Umbria, Regione dell'Umbria. pp. 130, ISBN 9788896277126
- **10.** Bencivenga, M, Di Massimo, G, Donnini, D and Tanfulli, M. 1995. Confronto tra la vegetazione delle tartufaie di Tuber aestivum Vitt., T. magnatum Pico e T. melanosporum Vitt. nell'Italia centrale. *Mic Ital*, 24(3): 87–95.
- **11.** Benucci, GMN, Bonito, G, Baciarelli Falini, L, Benicvenga, M and Donnini, D. 2012. “Truffles, timber, food, and fuel: sustainable approaches for multi-cropping truffles and economically important plants”. In *Edible Ectomycorrhizal Mushrooms*, Edited by: Zambonelli, A and Bonito, G. Soil Biology Series. Berlin, Heidelberg: Springer.
- **12.** Berg, B and McClaugherty, C. 2003. “Plant litter. Decomposition, humus formation, carbon sequestration”. 1–286. Berlin: Springer.
- **13.** Blasi, C, Carranza, ML, Filesi, L, Tilia, A and Acosta, A. 1999. Relation between climate and vegetation along a Mediterranean–Temperate boundary in central Italy. *Global Ecol Biogeogr*, 8: 17–27.
- **14.** Boddy, L. 2001. Fungal community ecology and wood decomposition processes in angiosperms: From standing tree to complete decay of coarse woody debris. *Ecol Bull*, 49: 43–56.
- **15.** Bonet, JA, Fischer, CR and Colinas, C. 2006. Cultivation of black truffle to promote reforestation and land-use stability. *Agron Sustain Dev*, 26: 69–76.
- **16.** Bragato G. 2010. Soils suitable for the white truffle. Proceedings from the 3rd International Congress on Tuber, Spoleto, Italy. pp. 140–146, ISBN 9788890512209
- **17.** Chang, ST. 1999. Global impact of edible and medicinal mushrooms on human welfare in the 21st century: Nongreen revolution. *Int J Med Mushrooms*, 1: 1–8.
- **18.** Chitwood, DJ. 2002. Phytochemical based strategies for nematode control. *Annu Rev Phytopathol*, 40: 221–249.

- **19.** Da Silva Coelho, J, de Oliveira, AL, de Souza, CGM, Bracht, A and Peralta, RM. 2010. Effect of the herbicides bentazon and diuron on the production of ligninolytic enzymes by Ganoderma lucidum. *Int Biodeter Biodegr*, 64: 156–161.
- **20.** Dahlberg, A, Genney, DR and Heilmann-Clausen, J. 2010. Developing a comprehensive strategy for fungal conservation in Europe: Current status and future needs. *Fungal Ecol*, 3: 50–64.
- **21.** Dai, Y-C, Yang, Z-L, Cui, B-K, Yu, C-J and Zhou, L-W. 2009. Species diversity and utilization of medicinal mushrooms and fungi in China (review). *Int J Medicin Mushr*, 11: 287–302.
- **22.** De Roman, M. 2010. “The contribution of wild fungi to diet, income and health: A world review”. In *Progress in mycology*, Edited by: Rai, M and Kövics, G. 327–348. London: Springer.
- **23.** Gao, Y, Zhou, S, Jiang, W, Huang, M and Dai, X. 2003. Effects of Ganopoly® (a Ganoderma lucidum polysaccharide extract) on the immune functions in advanced stage cancer patients. *Immunol Invest*, 32: 201–215.
- **24.** Garibay-Orijel, R, Córdova, J, Cifuentes, J, Valenzuela, R, Estrada-Torres, A and Kong, A. 2009. Integrating wild mushrooms use into a model of sustainable management for indigenous community forests. *Forest Ecol Manage*, 258: 122–131.
- **25.** Granetti, B, De Angelis, A and Materozzi, G. 2005. *Umbria terra di tartufi*, Terni: Umbriagraf per Regione Umbria.
- **26.** Gregori, A, Svagelj, M and Pohleven, J. 2007. Cultivation techniques and medicinal properties of Pleurotus species. *Food Technol Biotechnol*, 45: 238–249.
- **27.** Gunde-Cimerman, N. 1999. Medicinal value of the genus Pleurotus (Fr.) P. Karst. (Agaricales s.l., Basidiomycetes). *Int J Med Mushrooms*, 1: 69–80.
- **28.** Huhndorf, SM, Lodge, DJ, Wang, C-J and Stokland, JN. 2004. “Macrofungi on woody substrata”. In *Biodiversity of fungi. Inventory and monitoring methods*, Edited by: Mueller, GM, Bills, GF and Foster, MS. 159–163. New York: Elsevier Academic Press.
- **29.** Inoue, Y, Hata, T, Kawai, S, Okamura, H and Nishida, T. 2010. Elimination and detoxification of triclosan by manganese peroxidase from white rot fungus. *J Hazard Mater*, 180: 764–767.
- **30.** Iotti, M, Lancellotti, E, Hall, I and Zambonelli, A. 2010. The ectomycorrhizal community in natural Tuber borchii grounds. *FEMS Microbiol Ecol*, 72: 250–260.
- **31.** Jong, SC and Birmingham, JM. 1992. Medicinal benefits of the mushroom Ganoderma. *Adv Appl Microbiol*, 37: 101–134.
- **32.** Josefsson, T, Olsson, J and Östlund, L. 2010. Linking forest history and conservation efforts: Long-term impact of low-intensity timber harvest on forest structure and wood-inhabiting fungi in northern Sweden. *Biol Conserv*, 143: 1803–1811.
- **33.** Kropp, BR and Langlois, CG. 1990. Ectomycorrhizae in reforestation. *Can J Forest Res*, 20(4): 438–451.
- **34.** Küffer, N and Senn-Irlet, B. 2005. Influence of forests management on the species richness and composition of wood-inhabiting basidiomycetes in Swiss forests. *Biodivers Conserv*, 14: 2419–2435.
- **35.** La Guardia, M, Venturella, G and Venturella, F. 2005. On the chemical composition and nutritional value of Pleurotus taxa growing on Umbelliferous plants (Apiaceae). *J Agric Food Chem*, 53: 5997–6002.
- **36.** Marchetti, M, Tognetti, R, Lombardi, F, Chiavetta, U, Palumbo, GSellitto, M. 2010. Ecological portrayal of old-growth forests and persistent woodlands in the Cilento and Vallo di Diano National Park (southern Italy). *Plant Biosyst*, 144(1): 130–147.
- **37.** Martinez, AT, Speranza, M, Ruiz-Duenas, FJ, Ferreira, P, Camarero, SGuillen, F. 2005. Biodegradation of lignocellulosics: Microbiological, chemical and enzymatic aspects of fungal attack to lignin. *Int Microbiol*, 8: 195–204.

- **38.** Minter, D. 2011. Fungal conservation needs help from botanists. *Plant Biosyst*, 145(4): 945–949.
- **39.** Mizuno, T, Sakai, T and Chihara, G. 1995. Health foods and medicinal usages of mushrooms. *Food Rev Int*, 11: 69–81.
- **40.** Mueller, GM, Foster, M and Bills, GF, eds. 2004. “Biodiversity of fungi”. In *inventory and monitoring methods*, 777Burlington: Academic Press.
- **41.** Murat, C, Vizzini, A, Bonfante, P and Mello, A. 2005. Morphological and molecular typing of the below-ground fungal community in a natural Tuber magnatum truffle-ground. *FEMS Microbiol Lett*, 245: 307–313.
- **42.** Ntougias, S, Baldrian, P, Ehaliotis, C, Nerud, F, Merhautová, V and Zervakis, GI. 2012. Biodegradation and detoxification of olive mill wastewater by selected strains of the mushroom genera Ganoderma and Pleurotus. *Chemosphere*, 88(5): 620–626.
- **43.** Padulosi, S, Hodgkin, T, Williams, JT and Haq, N. 2002. “Underutilized crops: Trends, challenges and opportunities in the 21st century”. In *Managing plant genetic diversity*, Edited by: Engels, JMM, Ramanatha Rao, V, Brown, AHD and Jackson, MT. 323–338. Wallingford, Oxon: CABI Publishing.
- **44.** Palazzolo, E, Gargano, ML and Venturella, G. 2012. The nutritional composition of selected wild edible mushrooms from Sicily (southern Italy). *Int J Food Sci Nutr*, 63(1): 79–83. doi: 10.3109/09637486.2011.598850
- **45.** Persiani, AM, Audisio, P, Lunghini, D, Maggi, O, Granito, VMBiscaccianti, AB. 2010. Linking taxonomical and functional biodiversity of saproxylic fungi and beetles in broad-leaved forests with differing management histories in southern Italy. *Plant Biosyst*, 144(1): 250–261.
- **46.** Raglione M, Lorenzoni P, Owczarek M, Bonifazi A. 2010. A contribution to the characterization of the soils suitable for Tuber melanosporum and Tuber aestivum growth through mineralogical analysis of the clay fraction. Proceedings from the 3rd International Congress on Tuber, Spoleto, Italy. pp. 147–151, ISBN 9788890512209
- **47.** Rajala, T, Peltoniemi, M, Hantula, J, Mäkipää, R and Pennanen, T. 2011. RNA reveals a succession of active fungi during the decay of Norway spruce logs. *Fungal Ecol*, 4: 437–448.
- **48.** Rincón, A, de Felipe, MR and Fernández-Pascual, M. 2007. Inoculation of Pinus halepensis Mill. with selected ectomycorrhizal fungi improves seedling establishment 2 years after planting in a degraded gypsum soil. *Mycorrhiza*, 18: 23–32.
- **49.** Saitta, A, Bernicchia, A, Gorjón, SP, Altobelli, E, Granito, VMLosi, C. 2011. Biodiversity of wood-decay fungi in Italy. *Plant Biosyst*, 145(4): 958–968.
- **50.** Senn-Irlet, B, Heilmann-Clausen, J, Gennery, D and Dahlberg, A. 2007. *Guidance for conservation of macrofungi in Europe*, Strasbourg: Directorate of Culture and Cultural and Natural Heritage Council of Europe.
- **51.** Shah, PA and Pell, JK. 2003. Entomopathogenic fungi as biological control agents. *Appl Microbiol Biotechnol*, 61: 413–423.
- **52.** SPSS. Statistical Package for the Social Sciences. Inc. Headquarters, 233 S. Wacker Drive, 11th floor, Chicago, IL, 2009.
- **53.** Tsai, SY, Huang, SJ, Lo, SH, Wu, TP, Lian, PY and Mau, JL. 2009. Flavor components and antioxidant properties of several cultivated mushrooms. *Food Chem*, 113: 578–584.
- **54.** Varese, GC, Angelini, P, Bencivenga, M, Buzzini, P, Donnini, DGargano, ML. 2011. Ex situ conservation and exploitation of fungi in Italy. *Plant Biosyst*, 145(4): 997–1005. doi: 10.1080/11263504.2011.633119
- **55.** Wang, C, Sun, H, Li, J, Li, Y and Zhang, Q. 2009. Enzyme activities during degradation of polycyclic aromatic hydrocarbons by white rot fungus *Phanerochaete chrysosporium* in soils. *Chemosphere*, 77: 733–738.

- **56.** Wasser, SP. 2002. Medicinal mushrooms as a source of antitumor and immunomodulating polysaccharides. *Appl Microbiol Biotechnol*, 60: 258–274.
- **57.** Wasser, SP and Weiss, AL. 1999. Therapeutic effects of substances occurring in higher basidiomycetes mushrooms: A modern perspective. *Crit Rev Immunol*, 19: 65–96.
- **58.** Watling, R. 2005. “Fungal conservation: some impressions – A personal view. pp. 881–896”. In *The fungal community. Its organization and role in the ecosystem. 3rd ed. Mycology* Edited by: Dighton, J, White, JF and Oudemans, P. Vol. 23, 936
- **59.** Zambonelli, A and Di Munno, R. 1992. Indagine sulla possibilità di diffusione dei rimboschimenti con specie tartufigene: Aspetti tecnico-colturali ed economici. *Ecoplanning s.r.l.*, : 356
- **60.** Zervakis, GI and Koutrotsios, G. 2011. “Production of edible mushroom biomass on solid wastes and by-products of olive-oil processing”. In *Proceedings of the 5th European Bioremediation Conference*, Edited by: Kalogerakis, N and Fava, F. 1–5. Chania, Greece: TU-Crete. ID218
- **61.** Zervakis, G and Venturella, G. 2002. “Mushroom breeding and cultivation enhances ex situ conservation of Mediterranean *Pleurotus taxa*”. In *Managing plant genetic diversity*, Edited by: Engels, JMM, Ramanatha Rao, V, Brown, AHD and Jackson, MT. 351–358. Wallingford, Oxon: CABI Publishing.