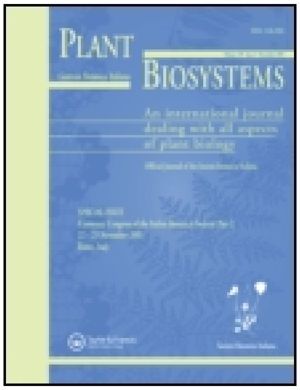

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Fungal biodiversity and in situ conservation in Italy

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THE CURRENT STATUS OF FUNGAL BIODIVERSITY IN ITALY

Fungal biodiversity and *in situ* conservation in Italy

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Abstract

A remarkable increase in knowledge of fungal biodiversity in Italy has occurred in the last five years. The authors report up-to-date numbers of fungi (*Basidiomycota* and *Ascomycota*) by regions together with distributional and ecological data on hypogeous fungi. Specific case studies such as alpine fungi, orchid mycorrhizas symbionts, invasive species, and the use of macrofungi as food by red squirrels are analyzed. *In situ* conservation strategies carried out on target species and/or taxonomic groups are also indicated.

Keywords: Ascomycota, Basidiomycota, *biodiversity, Italy, mycology*

Introduction

A year before the Earth Summit in Rio de Janeiro (Brazil), the Italian Botanical Society's Working Group for Mycology drafted a document containing two priority targets: increased mycological research and evaluation of fungal diversity in Italy with particular reference to larger fungi. As a result, regional checklists were published for Campania, Liguria, Sicily, and Tuscany, and these collectively contribute to the checklist of Italian fungi (*Basidiomycetes*) (Onofri et al. 2005). After that, a descriptive and iconographic review dealing of Italian *Basidiomycota* was released by Boccardo et al. (2008). It covered 1616 taxa of Agaricomycotina, focusing mainly on the Agaricales, Boletales, and Russulales.

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Several papers have also been published on aphyllophoroid fungi, updating the number of species and supplying new distributional and ecological data. Furthermore, a string of scientific papers, cited by Saitta et al. (2011), together with compiled checklists of the *Polyporaceae* s.l. and *Corticiaceae* s.l., reported in Bernicchia (2005) and Bernicchia and Gorjón (2010), respectively, collectively constitute an exhaustive revision of those fungi. From 1974 onwards, a remarkable number of studies on *Laboulbeniales* have been carried out with more than 200 taxa recorded and/or described (W. Rossi, pers. comm.). Ecological and distributional information about larger fungi is fragmented, being distributed through a huge number of papers published by a few mycologists employed in universities and a massive number of amateurs. For this reason, and taking into consideration the diversity of environments in Italy, the variety of geographical, climatic, geological, and pedological features, together with difficulties encountered in co-operation between academics and amateurs (Barron 2010), it is currently hard to evaluate how many fungal species the country really has.

Despite those problems, Italian mycologists have been able to contribute to different Biodiversity Assessment and Strategy initiatives (Blasi et al. 2005, 2009) with a list of 4296 *Basidiomycota* taxa, including 3973 species, 6 subspecies, 263 varieties, and 54 forms. On the basis of the checklist of *Basidiomycota*, 56 of those species are endemic and 87 taxa are rare. Preliminary redlists for macrofungi at a national and regional level have also been carried out (Venturella et al. 2002; Antonini & Antonini 2006). As reported in thematic contributions to the National Biodiversity Strategy in Italy (Blasi et al. 2009, 2010), the estimated number of larger fungi is currently 20,000 with at least 20 new species being described every year. Italian mycologists have also contributed to a project for mapping Important Plant Areas in Italy (the term "Important Fungus Areas" has not yet been adopted) by providing information about 42 species of macromycetes (36 with georeferenced data) and 394 georeferenced records highlighting eight important areas for fungi at a national level. Work by Italian mycologists has also resulted in *Pleurotus nebrodensis* (Inzenga) Quél., a critically endangered species (Venturella 2000; Gargano et al. 2011) being included in the IUCN Red List of Threatened Species (www.iucnredlist.org). Ongoing *ex situ* and *in situ* conservation strategies drawn up by mycologists working in the universities of Bologna, Palermo, Perugia, Siena, and Turin are devoted to target species and/or different taxonomic groups. They will be also presented in this article, together with other contributions on fungal biodiversity in Italy (Onofri et al. 2011; Persiani et al. 2011; Picco et al. 2011; Saitta et al. 2011; Varese et al. 2011).

These activities in assessing fungal diversity in Italy should be still considered as starting point and that has been a major reason for producing an updated report on the status of fungal diversity and mycological research in Italy.

Magnitude of biodiversity

There has been a remarkable increase in knowledge of fungal diversity in Italy over the last five years. An up-to-date estimate of the number of fungi per region, including data reported in Saitta et al. (2011), is provided in Figure 1 in comparison with data included by Onofri et al. (2005). Numbers from Sardinia are impressive (6500 taxa, M. Contu, pers. comm.) followed by Tuscany (3117 taxa). Over 2000

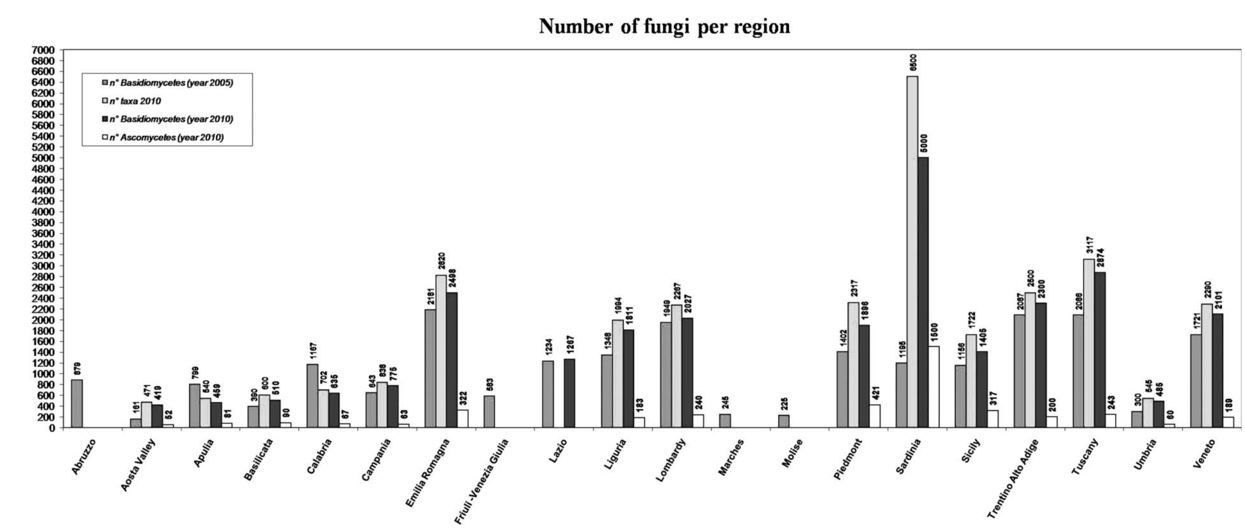

Figure 1. Number of fungi (*Basidiomycota* and *Ascomycota*) per region (update December 2010).

fungal taxa are reported for Emilia Romagna, Lombardy, Piedmont, Trentino-Alto Adige, and Veneto. In some Italian regions, the greatest limiting factor for documentation of fungal numbers is the lack of mycologists and/or the unavailability of records kept by amateur groups of mycologists. This is clearly evident for some regions (Figure 1) where the number of fungi has not changed from earlier estimates. Distributional and ecological information about hypogeous fungi is usually very limited in mycological studies. Detection of such fungi is usually only possible using dogs, and only a low number of semi-hypogeous fungi can be easily found by moving the superficial layer of plant litter. Distributional and ecological data on hypogeous fungi were provided in a monograph by Montecchi & Sarasini (2000), while other information is available from a number of scientific papers published by research groups working in the universities (Zambonelli & Morara 1994; Venturella & Bencivenga 1999; Cerone et al. 2000; Ceruti et al. 2003; Marino et al. 2003; Venturella et al. 2004, 2006; Saitta et al. 2008; Rana et al. 2010; Zotti et al. 2010b). The number of hypogeous fungi in Italy is currently 167 (including varieties and forms). These comprise 73 *Basidiomycota*, 85 *Ascomycota*, 3 *Zygomycota*, and 8 *Glomeromycota*. Recorded taxa belong to 55 genera and 28 families. The best represented families are *Pezizaceae* Dumort. (eight taxa), *Tuberaceae* Dumort. (five taxa), *Agaricaceae* Chevall. (four taxa), and *Pyronemataceae* Corda (four taxa). The best represented genera are *Tuber* P. Micheli ex F.H. Wigg. (27 taxa), *Elaphomyces* Nees (16 taxa), *Hymenogaster* Vittad. (14 taxa), *Hysterangium* Vittad. (eight taxa), *Rhizopogon* Fr. (eight taxa), *Genea* Vittad. (seven taxa) and *Melanogaster* Corda (six taxa). The current numbers of hypogeous fungi taxa by regions are reported in Figure 2.

In the case of hypogeous and semi-hypogeous fungi, the term "rare" is difficult to apply but the expansion of surveyed areas in Italy over the last 10 years and an increased knowledge of their ecology and distribution permit a better evaluation of their status. In particular, *Choiromyces meandriformis* Vittad., *Choiromyces venosus* (Fr.) Th. Fr., *Gauteria morchelliformis* Vittad., and *Picoa lefebvrei* (Pat.) Maire are rare in Umbria. In Emilia Romagna several species are found only rarely. These include the ascomycetes *Balsamia polysperma* Vittad., *Elaphomyces aculeatus* Vittad., *Elaphomyces anthracinus* Vittad., *Elaphomyces asperulus* Vittad., *Elaphomyces leveillei* Tul. & C. Tul., *Elaphomyces maculatus* Vittad., *Elaphomyces morettii* Vittad., *Elaphomyces septatus* Vittad., *Fischerula macrospora* Mattir., *Genea hispidula* Berk. ex Tul., *Hydnotrya cerebriformis* (Tul. & C. Tul.) Harkn., *Hydnotrya michaelis* (E. Fisch.) Trappe, *Leucangium carthusianum* (Tul. & C. Tul.) Paol., and *Tuber monosporum* (Mattir.) Vizzini. They also include the basidiomycetes *Chamonixia caespitosa* Rolland, *Gautieria otthii* Trog, *Gautieria trabutii* Chatin, *Gymnomyces ellipsosporus* (Zeller) Trappe, T. Lebel & Castellano, *Hymenogaster aromaticus* Velen., *Hymenogaster bulliardii* Vittad., *Hymenogaster calosporus* Tul., *Hymenogaster muticus* Berk. & Broome, *Hymenogaster rehsteineri* Bucholtz, *Hymenogaster thwaitesii* Berk. & Broome, *Hysterangium nephriticum* Berk., *Sclerogaster compactus* (Tul. & C. Tul.) Sacc., *Sclerogaster hysterangioides* (Tul. & C. Tul.) Zeller & C.W. Dodge, *Stephanospora caroticolor* (Berk.) Pat., and *Wakefieldia macrospora*

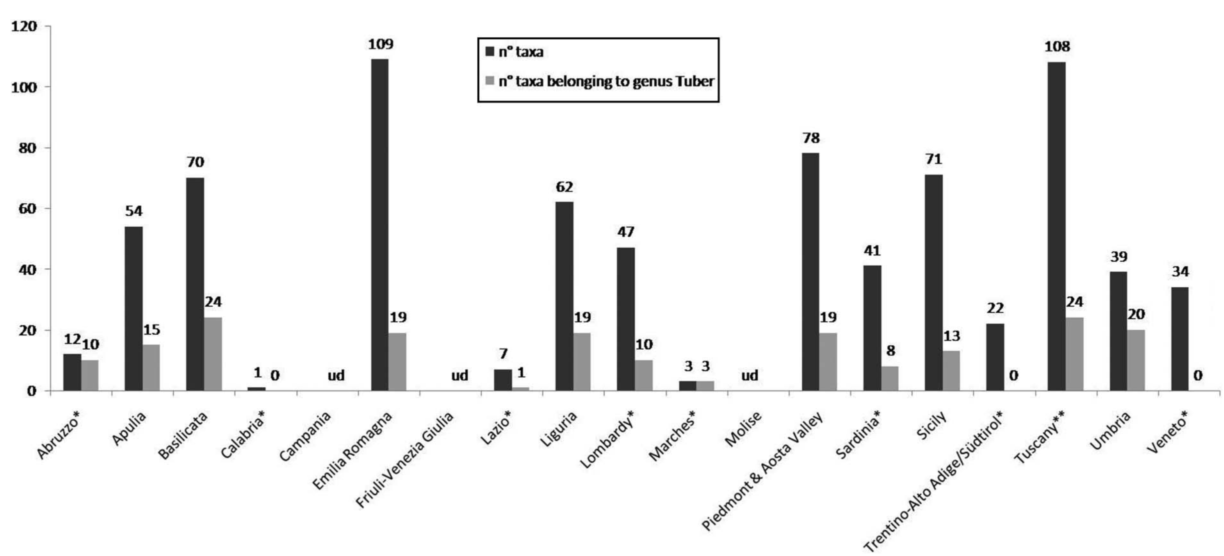

Figure 2. Number of hypogeous fungi per region and related number of *Tuber* species. [*Source: Montecchi & Sarasini (2000); **source: Gori (2005); ud = unknown data].

(Hawker) Hawker (Montecchi & Sarasini 2000; Zambonelli & Morara pers. comm.). In Liguria, *Alpova rubescens* (Vittad.) Trappe and *Rhizopogon rocabrunae* M.P. Martín are remarkable for their rarity (Zotti et al. 2010a,b). *A. rubescens*, also found in the nearby region Tuscany (Gori 2005), is characterized by a strict symbiotic association with members of the *Fagaceae* (*Fagus sylvatica* L., *Quercus* sp. pl., *Castanea sativa* Miller). According to the molecular study by Vizzini et al. (2010), the genus *Alpova* C.W. Dodge is clearly polyphyletic. *Alpova olivaceotinctus* (A.H. Sm.) Trappe and *Alpova alexsmithii* Trappe, fall within the *Suillineae*, whereas *A. rubescens*, *Alpova diplophloeus* (Zeller & C.W. Dodge) Trappe & A.H. Sm., *Alpova austroalnicola* L.S. Domínguez, and *Alpova trappe*i Fogel cluster within the *Paxillineae*. In this suborder, *A. rubescens* is not related to *A. diplophloeus*, type of the genus *Alpova* (Trappe, 1975), or to other *Alpova* species, and it probably represents a new and independent evolutionary line of hypogeous *Paxillineae*. Hypogeous fungi rare at a European level and found in Sicily include *E. citrinus*, *E. maculatus*, *F. macrospora*, *Gymnomyces xanthosporus* (Hawker) A.H. Sm., *Melanogaster umbriniglebus* Trappe & Guzmán, *Schenella simplex* T. Macbr., *S. pityophilus* (Malençon & Riousset) Estrada & Lado, *Sclerogaster compactus* (Tul. & C. Tul.) Sacc. and *Setchelliogaster tenuipes* (Setch.) Pouzar var. *rheophyllus* (Bertault & Malençon) G. Moreno & M.P. Martín (Saitta et al., 2009). *Schenella pityophilus* seems not to be rare in Salento (Apulia) or Basilicata, and in the last three years, several natural localities for *S. pityophilus* were found in those regions (Signore et al., 2008).

The high level of diversity of these hypogeous fungi arises mainly from oak woods, followed by pine and fir woods, hazel-tree cultivation, chestnut woods, beech woods, mixed woods with a prevalence of conifers and eucalyptus reafforestations. Many hypogeous fungi grow in the Mediterranean maquis ecosystems while *Genabea fragilis* Tul. & C. Tul. is usually collected under willow and poplar trees. In Mediterranean regions *Descomyces albus* (Berk.) Bougher & Castellano, *Hydnangium carneum* Wallr., *Hydnocystis clausa* (Tul. & C. Tul.) Ceruti, *Hysterangium inflatum* Rodway, *Reddellomyces donkii* (Malençon) Trappe, Castellano & Malajczuk, *S. tenuipes* are frequently collected on sandy dunes and considered are strictly linked to *Eucalyptus camaldulensis* Dehnh., *Acacia saligna* (Labill.) H.L. Wendl., *Pistacia lentiscus* L., and *Cistus* sp. pl. *Stephensia bombycina* (Vittad.) Tul. is reported additionally from public gardens close to lime trees and from certain broad-leaved forests in the northern part of Italy where *Tuber magnatum* Pico is also found (Tibiletti & Zambonelli, 1999, Mello et al., 2010). *Terfezia boudieri* Chatin and *T. claveryi* Chatin, strictly linked to *Helianthemum* sp. pl., grow in Sardinia and Apulia, in environments very similar to those of Algeria, France and Morocco. *Mattirolomyces terfezioides* (Mattir.) E. Fisch. is associated with disturbed areas and cultivated fields with *Ficus carica* L. and *Prunus* sp. pl. or *Asparagus* cultivation in the sandy littoral of the Adriatic (Montecchi & Lazzari, 1993). *Alpova diplophloeus* (Zeller & C.W. Dodge) Trappe & A.H. Sm. is usually collected in woods of *Alnus* sp. pl. (Montecchi & Sarasini, 2000). The endomycorrhizal *Gigaspora lazzarii* Montecchi, Ruini & G. Gross grows in mixed grasslands directly attached to *Lathyrus pratensis* L. subsp. *pratensis* stalks.

Italy boasts a long tradition in the study, harvesting and marketing of truffles. Researchers at the universities of Turin, Bologna, Perugia and L'Aquila have maintained this tradition and more recently other research teams have been set up in the Universities of Genova, Siena, Basilicata, and Palermo. *Tuber magnatum* has a scattered distribution in northern and central Italy and recently new localities were found in southern Italy, but not Sicily or Sardinia. *Tuber aestivum* Vittad. is a very common truffle distributed in broad-leaved and conifer woods in many regions, at different altitudes and in different ecological conditions. The quality of this truffle varies so greatly, depending on environmental conditions, that for a long time it was thought there were two different species: *T. aestivum* growing mainly in south Italy and *T. uncinatum* Chatin in the north. Molecular tools have now, however, demonstrated that there is only a single species which for reasons of nomenclatural priority should be called *T. aestivum* (Paolocci et al., 2004; Weden et al., 2005). *Tuber asa-foetida* Lesp. is an infrequent species mainly distributed in dry regions and linked to shrubs and herbaceous plants.

Distribution maps have been produced for truffles in some Italian regions. These include: Tuscany (Baglioni & Gardin 1998); Emilia Romagna (Tibiletti & Zambonelli, 1999; Biagioni et al. 2005); Abruzzo (De Laurentis & Spinelli, 2006); Piedmont (http://www.regione.piemonte.it/montagna/osservatorio/webgiscmcc/potenziali_tart.htm); Liguria (Pavarino et al., 2011). The scales available vary between 1:10,000 and 1:200,000. These maps are mainly based on overlay queries of data layers in a GIS environment. In particular, the map of the Ligurian pilot area is characterized by a high resolution being based on a raster grid detailed map with a spatial resolution of five metres.

Knowledge of Italian fungal diversity has also improved as a result of various specific case studies. Research has been carried out on communities of macrofungi which have been only infrequently studied in alpine habitats of Italy (Jamoni, 2008).

Dwarfism, expressed through a reduced number of gills and smaller sporocarps, is very common in alpine macrofungi and it is not clear whether a number of alpine fungal taxa with smaller sporocarps than their forest analogues should be considered as separate species (Boertmann & Knudsen 2006). Another interesting field of investigation is orchid mycorrhizas. Molecular methods, recently applied in several studies, have shown that mycoheterotrophic orchids have a strong mycorrhizal specificity to a narrow band of fungal taxa, such as *Russula* Pers., *Tuber* P. Micheli ex F.H. Wigg., and *Hymenogaster* Vittad. These, in most cases, form ectomycorrhizas with surrounding green plants (Selosse et al., 2004; Girlanda et al., 2006). Most fungi recorded as orchid mycorrhizal symbionts belong to the anamorphic form-genus *Rhizoctonia* DC. which is linked to a variety of teleomorphic genera. Among these, most of the orchid-associated *Rhizoctonia* species belong in the families *Ceratobasidiaceae*, *Sebacinaceae*, and *Tulasnellaceae* (Otero et al., 2002).

Evaluation of fungal diversity does not rule out investigation of alien invasive macrofungi. These are considered to be a major cause of global biodiversity loss (Pringle & Vellinga, 2006). One case study is the palaeotropical wood-inhabiting saprotroph *Favolaschia calocera* R. Heim (*Mycenaceae*). The Eighth International Mycological Congress, held in Australia, dedicated an online session to this fungus (IMC8 2006). *Favolaschia calocera* was found in 1999 in Multedo di Pegli (Genoa, Italy) in front of an important harbour area, and that collection was the first report of this species in Europe (Vizzini & Zotti, 2002). Vizzini et al. (2009) studied, by ITS molecular analysis, the origin of the strain found in Italy and provided new insights into the distribution and the spreading strategy of this species within Italy. *Favolaschia calocera* was observed growing on debris of various vascular plant species (*Pteridophytes*, Conifers, Mono- and Dicotyledons), thus showing it to be a polyphagous. It prefers ruderal sites along transport routes and other locations subject to human disturbance. In such places, the fungus can become dominant, particularly in late summer. The abundance of *F. calocera* basidiomes in these areas suggests it may be displacing native wood-inhabiting species, and field studies on wood inhabiting macrofungi of these Italian sites have shown a very poor level of biodiversity. On the basis of field observations and phylogenetic analysis it seems likely that the first recorded occurrences of *F. calocera* in Italy probably arrived from New Zealand, via timber. Inter specimen genetic comparison mirrors a low polymorphism, as suggested by the identity of their ITS sequences. The territorial expansion of *F. calocera* is probably due to a combination of factors including its selfing life strategy and the production of antifungal compounds (strobilurins and oudemansins), as well as its ability to fill ecological niches emptied by human disturbance. Its colonizing strategy relies on wind dispersal of basidiospores.

Bertolino et al. (2004) investigated the importance of macrofungi as a food resource for red squirrels (*Sciurus vulgaris* L. 1758) in subalpine conifer forests in the Gran Paradiso National Park (Aosta Valley) and the role of the species as a spore dispersal agent. They determined the frequency of occurrence, species diversity, and abundance of fungal spores in dung samples collected in two mixed forests of *Picea excelsa* (Lam.) Link and *Larix decidua* Miller. Spores found in spring all belongs to *Balsamia* Vittad., *Elaphomyces* Nees, *Gautieria* Vittad., *Hysterangium* Vittad. and *Rhizopogon* Fr., except in one case when spores of *Boletus* L. were found. In summer and autumn, spores of *Boletus*, *Laccaria* Berk. & Broome, *Balsamia*, *Elaphomyces*, *Gautieria*, *Hysterangium*, *Hydnotrya* Berk. & Broome, *Hymenogaster* Vittad., *Leucogaster* R. Hesse, *Melanogaster* Corda and *Rhizopogon* were detected. *Rhizopogon* was the most frequent genus consumed by squirrels (56.6% of all dung samples), followed by *Gautieria* (44.4%), *Balsamia* (33.3%), and *Hysterangium* (25.8%). *Boletus* and *Laccaria* were present in dung with a mean frequency of 18.5 and 8.0%, respectively.

In situ *conservation*

Fungi are still very seldom legally protected and examples of *in situ* conservation remain infrequent. Courtecuisse (2001) recognized three types of conservation strategies: a) conservation of natural habitats, b) establishment of mycological reserves, and c) use of ecological corridors. In Italy, conservation of natural habitats is determined through a project sponsored by the Italian Ministry for the Environment and Protection of the Land and Sea aimed at mapping Important Plant Areas in Italy (Blasi et al. 2009, 2010), and for protecting fungi, conservation of their habitats is the most important tool (Courtecuisse, 2001). A list of rare, threatened and/or endemic fungi species was recently compiled by national experts to fulfill one of the three criteria for selection of good sites: criterion A is based on the presence of species from the European Red List, lists of the Habitat Directive and the Bern Convention. Analysing information emerging from the Checklist of Italian Fungi (*Basidiomycetes*) and the preliminary Red Lists (Onofri et al., 2005; Venturella et al., 2002) and taking into account the Bern Convention, 42 macromycetes have been chosen. Of these 26 are among the 33 species proposed for the Bern Convention appendix, while *Alnicola tantilla* (J. Favre) Gulden is a very rare basidiomycete growing in alpine woods of Trentino Alto Adige and *Inocybe tricolor* Kühner, reported from Lombardy and Veneto, is evaluated as Least Concern (LC) using the IUCN categories (D. & M. Antonini, pers. comm). Further attempts to select important sites for fungi have been made by Leonardi et al. (2010), Parmasto et al. (2004), Perini & Laganà (2003), Perini & Salerni (2004), Perini et al. (in press). Fungi can increase the interest of stakeholders in protecting some areas. This was the case in a study carried out in mountain peatbogs (a habitat listed in the EU project Natura 2000) showing not only the presence of rare and threatened vascular plants and bryophytes but also of interesting macromycetes linked to sphagnum communities (Perini et al., 2002). Similarly, in the Simbruini Mountains Natural Park, the widest protected area in Latium, three hundred and forty-seven species of fungi were recorded (Doveri et al. 2005; Granito & Lunghini 2004, 2006, 2011; Guzman et al. 2006). Particularly noteworthy was the presence of numerous grassland species of the genera *Entoloma* (Fr.) P. Kumm., *Hygrocybe* (Fr.) P. Kumm., and *Camarophyllus* (Fr.) P. Kumm., all considered to be indicators of grassland suitable for conservation. Another noteworthy result was the finding of *Poronia punctata* (L.) Fr., considered one of the rarest fungi in Europe and therefore included in the IUCN/WCMC RDL, and of two other species, *Sarcosphaera coronaria* (Jacq.) J. Schröt. and *Phylloporus rhodoxanthus* (Schwein.) Bres., both proposed for inclusion in Appendix I of the Bern Convention on the Conservation of European Wildlife and Natural Habitats. The first *in situ* collection of benefcial symbiotic microorganisms (arbuscular mycorrhizal fungi) in the world, located in an integrally protected area of coastal sand dunes, within the UNESCO Biosphere Reserve "Selva Pisana", in Tuscany, Italy was recently established by Turrini et al. (2008). A pilot project for implementing IUCN categories and criteria for the editing of Red Lists (Rossi et al., 2008, Dahlberg & Mueller 2011) was carried out by relevant Working Groups of the Italian Botanical Society (WG for Conservation of Nature, WG for Mycology, WG for Bryology, WG for Lichenology and WG for Floristics). *Boletus dupainii* Boud. and *Psathyrella ammophila* (Durieu & Lév.) P. D. Orton were selected as representatives of the fungi by Perini & Venturella (2008a,b). *Boletus dupainii* is a rare symbiont of broad-leaved plants with fruiting only occasionally. The species is mainly threatened by reforestation with conifers and by silvicultural management of woods. According to IUCN criterion A, *B. dupainii* should be considered as Vulnerable (VU A2c) since silvicultural practices are causing 30% reductions of natural habitat. According to criterion B the species comes out as Vulnerable [VU B2ab (ii, iii)] since the area of distribution is extremely fragmented and less than 2,000 km^2. The regional status of *B. dupainii* is Not Evaluated (NE) at the national level and Endangered (EN) in Tuscany. Conservation strategies for this fungus are mainly oriented towards protection of its habitat included in parks and nature reserves. *Psathyrella ammophila*, included in Red Lists of the Czech Republic, Germany, Hungary, Latvia, Norway, Poland and Sweden, is a common species in Italy growing in sandy coastal areas. Heavy pressure from human use of coastal sandy dune environments has resulted in *P. ammophila* being rated as Near threatened (NT) (A2c) on the basis of criterion A and Vulnerable [VU B2ab (iii)] because of suspected reduction of population size and an estimated 15% progressive reduction of habitat. *In situ* conservation strategies for this fungus are similar to those for *B. dupainii*. In the IUCN Red List of Threatened Species, *Pleurotus nebrodensis* (Inzenga) Quél., is listed as CR (Critically Endangered) because the area where it is found is less than 100 kmô˙, the population is severely fragmented, and there is a decline in the number of localities and mature individuals. This mushroom only occurs in northern Sicily, growing in scattered localities in the Madonie mountains from 1200 to 2000 m in altitude. It is estimated that fewer than 250 individuals reach maturity each year and the population is decreasing (Gargano et al., 2011). *Pleurotus nebrodensis* grows on limestone substrates, in pastures containing *Cachrys ferulacea* (L.) Calestani, a member of the *Apiaceae* or celery family. The population declines are due to the increasing number of mushroom gatherers, both professional and amateur, who are encouraged by the high price this mushroom commands. In addition to this increased human pressure on the remaining natural populations, unripe fungi are usually collected. The conservation action for this fungus is legally binding since the Madonie Park administration has issued rules controlling mushroom collecting within the Park. In particular, collection of *P. nebrodensis* is totally forbidden in zone A of the Park which is an integral reserve area. In other zones the collection of unripe mushrooms (i.e., basidiomata less than 3 cm in diameter) is forbidden. Other *in situ* conservation action involves inoculation of roots of the associated plant *C. ferulacea* with grain mycelia of *P. nebrodensis* in the hope of increasing mushroom fructification in the wild.

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References

Antonini D, Antonini M., editors. 2006. Libro rosso dei macromiceti della Toscana. Dal censimento alla redlist. ARSIA Regione Toscana, Firenze, pp. 344 (CDROM).

Baglioni F, Gardin L. 1998. Carta della vocazione naturale del territorio toscano alla produzione di tartufo scorzone. In: Mazzei, editor. I Tartufi in Toscana. ARSIA, Regione Toscana, Firenze, pp. 167–170.

Barron ES. 2010. The emergence and coalescence of fungal conservation social networks in Europe and the USA. Fungal Ecol XXX: 1–10.

Bernicchia A. 2005. *Polyporaceae* s.l. Fungi Europaei. 10th ed. Alassio, Italy: Candusso. p. 808.

Bernicchia A, Gorjón SP. 2010. *Corticiaceae* s.l Fungi Europaei. 12th ed. Alassio, Italy: Candusso. p. 1008.

Bertolino S, Vizzini A, Wauters LA, Tosi G. 2004. Consumption of hypogeous and epigeous fungi by the red squirrel (*Sciurus vulgaris*) in subalpine conifer forests. Forest Ecol Manage 202: 227–233.

Biagioni V, Carletti G, Patrizzoli W, Marletto V, Zambonelli A. 2005. La cartografia delle aree tartuficole della provincia di Modena. In: G. Mondadori, editor. Appennino Modenese Terre da Tartufo. Editoriale Giorgio Mondadori. pp. 44 59.

Boitani L, La Posta S, Manes F, Marchetti M. 2005. Stato della biodiversità in Italia. In: Blasi C, editor. Contributo alla strategia nazionale per la biodiversità. Roma: Palombi. pp. 446.

Blasi C, Marignani M, Copiz R, Fipaldini M. editors. 2009. A thematic contribution to the National Biodiversity Strategy. Mapping the Important Plant Areas in Italy. Rome: Palombi & Partner s.r.l. p. 31.

Blasi C, Marignani M, Copiz R, Fipaldini M, Del Vico E, editors. 2010. Le aree importanti per le piante nelle regioni d'Italia: il presente e il futuro della conservazione del nostro patrimonio botanico. Roma: Progetto Artiser. p. 224.

Boccardo F, Traverso M, Vizzini A, Zotti M. 2008. Funghi d'Italia. Bologna: Zanichelli. p. 623.

Boertmann D, Knudsen H, editors. 2006. Arctic and Alpine mycology 6. Proceedings of the Sixth International Symposium on Arcto-Alpine Mycology (ISAM 6), Greenland, 11–21 August 2000. Danish Polar Center. – Meddr Greenland. Bioscience 56: 161.

Cerone G, Marino R, Rana GL. 2000. Studi sui funghi ipogei della Basilicata. Riv Micol 4: 333–346.

Ceruti A, Fontana A, Nosenzo C. 2003. Le specie europee del genere *Tuber*, una revisione storica. Torino: Regione Piemonte. p. 467.

Courtecuisse R. 2001. Current trends and perspectives for the global conservation of fungi. In: Moore D, Nauta MM, Evans SE, Rotheroe M. editors. Fungal Conservation. Issues and solutions. Cambridge, UK: Cambridge University Press. pp. 7–18.

Dahlberg A, Mueller GM. 2011. Applying IUCN red-listing criteria for assessing and reporting on the conservation status of fungal species. Fungal Ecol 4: 147–162.

De Laurentis G, Spinelli D. 2006. Carta della vocazionalità tartuficola della Regione Abruzzo. Lanciano, CH: ARSSA. p. 95.

Doveri F, Granito VM, Lunghini D. 2005. Nuovi ritrovamenti di *Coprinus* s.l. fimicoli in Ialia. – new findings of fimicolous *Coprinus* s.l. in Italy. Riv Micol 4: 319–340.

Gargano ML, Saitta A, Zervakis GI, Venturella G. 2011. Building the jigsaw puzzle of the critically endangered *Pleurotus nebrodensis*: Historical collection sites and an emended description. Mycotaxon 115: 107–114.

Girlanda M, Selosse MA, Cafasso D, Brilli F, Delfine S, Fabbian R, et al. 2006. Inefficient photosynthesis in the Mediterranean orchid *Limodorum abortivum* is mirrored by specific association to ectomycorrhizal *Russulaceae*. Mol Ecol 15: 491–504.

Gori L. 2005. Funghi ipogei della Lucchesia, di altre province italiane e dall'estero. Pacini Fazzi: Maria. p. 320.

Granito VM, Lunghini D. 2004. Some *Psilocybe* species from Monti Simbruini Regional Natural Park, Italy. Micol Veget Medit 19: 115–130.

Granito VM, Lunghini D. 2006. Updated observations on *Poronia punctata*. Micol Veget Medit 21: 71–76.

Granito VM, Lunghini D. 2011. Biodiversity of macrofungi in the beech forests and calcareous grasslands of the Simbruini Mountains Regional Park (central Apennines, Italy). Plant Biosyst 145: 381–396.

Guzman G, Granito VM, Lunghini D, Gandara E, Ramirez-Guillen F. 2006. An emendation of *Psilocybe liniformans*, an uncommon species found in the Central Apennines (Italy). Micol Veget Medit 21: 117–122.

IMC8. 2006. International Mycological Congress, Cairns, Australia – Fungus of the month July 2005, *Favolaschia calocera*. Available: http://www. rbg.vic.gov.au/research_and_conservation/fungi. Accessed Nov 2011 3.

Jamoni PG. 2008. Funghi alpini delle zone alpine superiori e inferiori. Associazione Micologica Bresadola. Trento: Fondazione, Centro Studi Micologici. p. 544.

Leonardi P, Salerni E, Pecoraro L, Perini C. 2010. Riserve per funghi: l'esperienza toscana nel progetto IPAs (important plant areas). Micol Ital 39: 3–8.

Marino R, Cerone G, Rana GL. 2003. Studi sui funghi ipogei della Basilicata. II contributo. Rivista di Micologia. Associazione Micologica Bresadola Trento, 1: 53–62.

Mello A, Miozzi L, Vizzini A, Napoli C, Kowalchuk G, Bonfante P. 2010. Bacterial and fungal communities associated with *Tuber magnatum*-productive niches. Plant Biosyst 144: 323–332.

Montecchi A, Lazzari G. 1993. Atlante fotografico dei funghi ipogei. Chiavi di determinazione a cura di G. Gross. – Trento : Associazione Micologica Bresadola; Vicenza: Centro studi micologici.

Montecchi A, Sarasini M. 2000. Funghi ipogei d'Europa. Associazione Micologica Bresadola, Fondazione Centro Studi Micologici. Vicenza. p. 714.

Onofri S, Bernicchia A, Filipello Marchisio V, Padovan F, Perini C, et al. 2005. Checklist dei funghi italiani – Checklist of Italian fungi, Basidiomycetes. Sassari: C. Delfino ed. pp. 1–380.

Onofri S, Anastasi A, Del Frate G, Di Piazza S, Garnero N, Guglielminetti M, et al. 2011. Biodiversity of rock, beach and water fungi in Italy. Plant Biosyst 145: 981–990.

Otero JT, Ackerman JD, Bayman P. 2002. Diversity and host specificity of endophytic *Rhizoctonia*-like fungi from tropical orchids. Am J Bot 89: 1852–1858.

Paolocci F, Rubini A, Riccioni C, Topini F, Arcioni S. 2004. *Tuber aestivum* and *Tuber uncinatum*: Two morphotypes or two species? FEMS Microbiol Lett 235: 109–115.

Parmasto E, Perini C, Rahko T. 2004. Attempts to introduce fungi in nature conservation activities. Fourth European Conference on the Conservation of Wild Plants, Valencia 17–20 September. p. 7 (book of abstract).

Pavarino M, Rellini I, Bozzano M, Mariotti MG, Zotti M. 2011. Indicator-based approach for mapping and assessing *Tuber magnatum* Pico presence in Western Liguria (Italy). Atti del 3° Convegno Internazionale sul Tartufo, Spoleto, 2008. pp. 273–281.

Perini C, Bonini I, Romagnoli P, Antonini D, Antonini M. 2002. Macrofungi and bryophytes of montane mires (Tuscany, Italy): Organisms worthy of conservation. Feddes Repertorium 113: 152–160.

Perini C, Laganà A. 2003. Towards selection of IFA (Important Fungus Areas): the Italian experience. XIV Congress of European Mycologists, Yalta, Ukraine, 22–27 September. p. 35 (book of abstract).

Perini C, Leonardi P, Pecoraro L, Salerni E. in press. The important plant areas program from a mycological point of view: The regional experience in an European context. Fitosociologia 48. suppl. 1.

Perini C, Salerni E. 2004. Identificazione di aree particolarmente importanti per la conservazione dei funghi. 99° Congresso della Società Botanica Italiana, Torino 22–24 settembre. p. 175.

Perini C, Venturella G. 2008a. Funghi: *Boletus dupainii* Boud. In: Rossi G, Gentili R, Abeli T, Gargano D, Foggi B, Raimondo FM et al., editors. Flora da conservare. Iniziativa per l'implementazione in Italia delle categorie e dei criteri IUCN (2001) per la redazione di nuove Liste Rosse. Inform Bot Ital 40: 7–185.

Perini C, Venturella G. 2008b. Funghi: *Psathyrella ammophila* (Durieu et Lév.) P.D. Orton. pp. 151–152. In: Rossi G, Gentili R, Abeli T, Gargano D, Foggi B, Raimondo FM, editors. Flora da conservare. Iniziativa per l'implementazione in Italia delle categorie e dei criteri IUCN (2001) per la redazione di nuove Liste Rosse. Inform Bot Ital 40: 7–185.

Persiani AM, Tosi S, Del Frate G, Granito VM, Guglielminetti M, Lunghini D, et al. 2011. High spots for diversity of soil and litter microfungi in Italy. Plant Biosyst 145: 972–980.

Picco AM, Angelini P, Ciccarone C, Franceschini A, Ragazzi A, Rodolfi M, et al. 2011. Biodiversity of emerging pathogenic and invasive fungi in plants, animals and humans in Italy. Plant Biosyst 145: 991–999.

Pringle A, Vellinga EC. 2006. Last chance to know? Using literature to explore the biogeography and invasion biology of the death cap mushroom *Amanita phalloides* (Vaill. ex Fr.:Fr.) Link. Biol Invasions 8: 1131–1144.

Rana GL, Signore SF, Fascetti S, Marino R, Mang SM, Zotta T. 2010. Seconda segnalazione del *Pachyphloeus prieguensis* in Italia ed acquisizioni recenti sui funghi ipogei lucani e pugliesi. Micol Veg Medit 25: 47–80.

Rossi G, Gentili R, Abeli T, Gargano D, Foggi B, Raimondo FM, et al. editors. 2008. Flora da conservare. Iniziativa per l'implementazione in Italia delle categorie e dei criteri IUCN (2001) per la redazione di nuove Liste Rosse. Inform. Bot. Ital 40: 7–185.

Saitta A, Gargano ML, Morara M, Ilice M, Venturella G. 2008. The hypogeous fungi from Sicily (southern Italy): New additions. Mycol Balcanica 5: 147–152.

Saitta A, Gargano M, Venturella G. 2009. *Elaphomyces citrinus* and *Elaphomyces maculatus* in Sicily (Southern Italy). Mycotaxon 109: 269–274.

Saitta A, Bernicchia A, Gorjón SP, Altobelli E, Granito VM, Losi C, et al. 2011. Biodiversity of wood-decay fungi in Italy. Plant Biosyst 145: 961–971.

Selosse MA, Faccio A, Scappaticci G, Bonfante P. 2004. Chlorophyllous and achlorophyllous specimens of *Epipactis microphylla* (*Neottieae*, *Orchidaceae*) are associated with ectomycorrhizal septomycetes, including truffles. Microbial Ecol 47: 416–426.

Signore SF, Rana GL, Lolli G, Laurita A. 2008. *Schenella pityophyla*, un raro gasteromicete rinvenuto nel Salento. Micol Veget Medit 23: 135–145.

Tibiletti E, Zambonelli A. 1999. I tartufi nella provincia di Forlì-Cesena. Bologna: Patron. p. 178.

Tkalčec Z, Mešić A, Antonić O. 2005. Survey of the gasteral *Basidiomycota* (fungi) of Croatia. Nat Croat 14: 99–120.

Trappe JM. 1975. A revision of the genus *Alpova* with notes on *Rhizopogon* and the *Melanogastraceae.*Beih. Nova Hedwigia 51: 270–309.

Turrini A, Avio L, Bedini S, Giovannetti M. 2008. *In situ* collection of endangered arbuscular mycorrhizal in a Mediterranean UNESCO biosphere reserve. Biodivers Conserv 17: 643–657.

Varese GC, Angelini P, Bencivenga M, Buzzini P, Donnini D, Gargano ML, et al. 2011. *Ex-situ* conservation and exploitation of fungi in Italy. Plant Biosyst 145: 1000–1008.

Venturella G. 2000. Typification of *Pleurotus nebrodensis.* Mycotaxon 75: 229–231.

Venturella G, Bencivenga M. 1999. Distribution and ecology of *Tuber borchii* in Sicily. Doc Mycol 29: 59–61.

Venturella G, Bernicchia A, Filipello Marchisio V, Pacioni G, Perini C, Onofri S, et al. 2002. Harmonisation of Red Lists in Europe: Some critical fungal species from Italy. Seminar on "The harmonisation of National Red Lists in Europe", 27–28 novembre. Leiden, the Netherlands. p. 46–47.

Venturella G, Saitta A, Sarasini M, Montecchi A, Gori L. 2004. Contribution to the knowledge of hypogeous fungi from Sicily (S-Italy). – Fl. Medit 14: 275–284.

Venturella G, Pecorella E, Saitta A, Zambonelli A, Morara M. 2006. Ecology and distribution of hypogeous fungi from Sicily (southern Italy). Cryptogamie, Mycologie 27: 201–217.

Vizzini A, Zotti M. 2002. *Favolaschia calocera*, a tropical species collected in Italy. Mycotaxon 82: 169–176.

Vizzini A, Zotti M, Mello A. 2009. Alien fungal species distribution: the study case of *Favolaschia calocera.* Biol Invasions 11: 417–429.

Vizzini A, Zotti M, Ryman S, Ghignone S. 2010. Typification of *Octaviania rubescens* (*Paxillineae*, *Boletales*) and phylogenetic hypotheses for the genus *Alpova.* Mycologia 102: 967–975.

Weden C, Danell E, Tibell L. 2005. Species recognition in the truffle genus *Tuber* – the synonyms *Tuber aestivum* and *Tuber uncinatum*. Environ Microbiol 7: 1535–1546.

Zambonelli A, Morara M. 1994. Le specie di *Tuberales* dell'Emilia Romagna, ecologia e distribuzione. Natura e Montagna 4: 9–32.

Zotti M, Di Piazza S, Vizzini A. 2010a. First records of *Rhizopogon rocabrunae* and *R. pumilionum* (*Boletales*) from Italy. Mycotaxon 113: 291–296.

Zotti M, Di Piazza S, Vizzini A, Pavarino M, Mariotti MG. 2010b. Hypogeous fungi in Liguria (Italy): distribution and ecology. Cryptogamie Mycologie 31: 47–57.