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DAVIDE PETTENELLA · MARGARIDA TOMÉ

NON-WOOD FOREST PRODUCTS IN EUROPE

ECOLOGY AND MANAGEMENT OF MUSHROOMS, TREE PRODUCTS, UNDERSTORY PLANTS AND ANIMAL PRODUCTS

OUTCOMES OF THE COST ACTION FP1203 ON EUROPEAN NWFPS

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6. Mushrooms & truffles

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6.1 Introduction

Fungi are one of the most diverse groups worldwide (Tedersoo *et al.* 2014), playing a key role in the ecosystem functioning. Their relevance is not exclusively restricted to their ecological role, but also to the economic potential mainly as a food source of their fruit bodies. Wild forest mushrooms are among the most important non-timber forest products and they have been collected and used by humans worldwide for thousands of years. They have been valued as food, traditional source of natural bioactive compounds, medicine, tinder, handicrafts, cloths, ritual praxis, spiritual enlightenment, recreation and a number of other purposes ranging from insecticides to soil fertilizers (Wu *et al.* 2016; Yamin-Pasternak 2011; Peintner and Pöder 2000). Archaeological findings also suggest that mushrooms have been used in religious ceremonies in many ancient cultures. Their sudden appearance after rain and thunderstorms, short life, polysemy and marginal place between the pure and the dangerous are the main reasons for connecting them with the supernatural and the spirits world. One of the most recognizable and widely encountered mushrooms in popular culture is the magic red mushroom with the white warts, which illustrates children books, the fly agaric (*Amanita muscaria*). It has been claimed to be the basic component of *soma*, the good narcotic of ancient India, and is also known for its hallucinogenic and magico-religious use by the Siberian shamans, the Mayas, the Aztec Indiand, the modern inhabitants of Mesoamerica, while it is well known worldwide in modern times for its psychoactive properties (Schultes *et al.* 1992; Lowy 1974) together with other psychoactive magic mushrooms, e.g. *Psilocybe* spp.

Fungi play also an important role in our life as a food. Yeasts are essential for the making of wine, bread and beer, molds are important for cheese and sausage production, as well as for fermentation (Miso, Tempeh, Sufu, Soja-Sauce) while mushrooms are known to be used as food from archaeological records that associate edible mushrooms with people who lived in Chile 13 000 years ago (Boa 2004). According to Boa (2004) there are over 200 mushroom genera, which contain species of use to people worldwide, of which 46% (a total of 1154 species recorded from 85 countries) are used as food, 20% have medicinal properties and almost 10% have at present other uses (e.g. ceremonial, as tinder, as natural dyes).

Nowadays, wild edible mushrooms are collected and traded in more than 80 countries worldwide. Furthermore, there is a growing awareness that mushrooms make up a vast, and generally untapped, source of new pharmaceutical products (Wu *et al.* 2016; Boa 2004). In Africa, almost half of the countries have some tradition of wild edible mushroom collection, particularly, in central and southern regions, where mushrooms provide a notable contribution to diets during the months of the year when the food supply is extremely low. Moreover, nearly 15% of them also export small quantities of wild edible mushrooms (e.g. cep, desert truffles, matsutake), mainly to European countries, such as Italy but also to China and Japan. Likewise, 45% of Asian countries also possess traditions of wild edible mushroom picking and consumption, mainly China and Russia and surrounding countries. Also, near 20% of Asian countries export morels to nearby countries and/or matsutake to Japan, a major importer of this mushroom species. China stands out as the world leading producer, user and exporter, mainly of matsutake and other medicinal mushrooms used in traditional Chinese medicine. Regarding America, only few countries have strong traditions of collecting and consuming wild edible fungi, such as Mexico, Guatemala and Honduras. In the United States of America (USA) and Canada, wild mushroom collection is much lower than that suggested by the vast mycological knowledge available and mostly centred in the Pacific Northwest, yet, both are major exporters of matsutake to Japan. In more than 50% of all the South American countries, no information on wild edible mushroom picking and consumption is available. A few countries (e.g. Brazil and Ecuador) do export small quantities of edible mushrooms like *Agaricus blazei* (to Japan) and pine bolete (to USA), whereas Argentina and Chile have a localized consumption of morels and/or *Cyttaria* spp. As for Oceania, with the exception of Australia, where useful accounts of aboriginal use do exist, from the great majority of countries we do not have information about collection and consumption of wild edible mushrooms or only have weak traditions (e.g. Fiji, New Zealand and Papua New Guinea). However, New Zealand has a recognized production of *Agaricus* spp. and *Tuber* spp. (Boa 2004).

In Europe, there is a long tradition of collecting wild edible mushrooms, mainly for self-consumption. This fact is well documented since Roman times, but recent archaeological findings (e.g. the "Red Lady" of Cantabria) revealed that the consumption of wild edible mushrooms in Europe is older, dating back to the Palaeolithic (Power *et al.* 2015). Nowadays, it is clear that most of the European countries value their mycological resources and more than 50% have some sort of legislation or guidelines for mushroom harvesting, consumption and commercialization (Peintner *et al.* 2013). Generally, countries fall into two categories: first, nations with weak economies, usually with a significant local tradition of using wild edible mushrooms; second, wealthier countries that import but may not have a strong tradition of collecting. Romania is an example of the first group and the Netherlands an example of the second. Southwestern and Central European populations reveal a mycophilic attitude and have strong traditions related to the consumption of many different species of edible mushrooms. For instance, edible mushroom *taxa* listed to be commercialized in France (122), Switzerland (114), Spain (93), Austria (92) and Italy (73) are much higher than in Croatia (27), Bosnia and Herzegovina (18) and Serbia (15). The overall diversity of edible mushrooms authorized to be commercialized in Europe is very high (268, 60 of which can be cultivated). Remarkably, only two fungal *taxa* are on all the lists: Cep (*Boletus edulis* complex), and chanterelle (*Cantharellus cibarius*) (Peintner *et al.* 2013).

The mycophilic or mycolatrous (mushroom-loving) versus mycophobic (mushroom-fearing) dichotomy is based on the work of Wasson and Wasson (1957) who created a scale of mycophilia and mycophobia syndromes and attempted to place on this scale different countries around the world based on their own studies. This dichotomy was criticized for overgeneralization, polarization and for giving little room for specific communities or individuals differentiations (Yamin-Pasternak 2011; Letcher 2007). Detailed studies of mushroom lore and the linguistic diversity of mushroom local names suggest that even mushrooms are understudied because of their role as occasional or famine food of the poor people have had their place in many local cultures and gastronomies (Stara *et al.* 2016; Vrachionidou 2007).

Wild edible mushrooms represent a significant growing dietary supplement for many European populations and an important marketable product for rural economies in many countries. Some populations have a strong tradition of wild edible fungi collection and consumption, given that mushrooms constitute a necessary portion of their diets. Moreover, selling mushrooms is a very common occupation which constitutes an extra income, often tax free, among the impoverished populations or/and in countries with weakened economies. Selling mushrooms seems a widespread tradition in Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, N. Macedonia, Poland and Russia among others. Contrary, in Austria, Denmark, Germany, Norway, Sweden, and Switzerland, picking mushrooms is rather a recreational activity mostly for personal consumption. Here, mycophilic people are often organized in mycological societies or local scientific groups for exchanging and sharing taxonomic knowledge on mushrooms and organizing mushroom forays (Information about different mycological societies in Europe may be found on the homepage of the European Mycological Association (EMA 2017)). In some countries (e.g. Finland, Italy, France, Spain and Portugal) there are clear distinct local behaviours among the populations: in some districts people are afraid and refuse to eat wild mushroom because of fear, while in others people love eating mushrooms. There are case studies (e. g. France, Spain, Finland, Switzerland, Czech Republic) that show the economic importance of wild edible mushroom exploitation in rural areas. For instance, Sisak *et al.* (2016) demonstrates that the material value of collected mushrooms could surpass 12% of the average annual value (per hectare) of the intensive forestry timber production and hence that forest management for timber production can be smoothly combined with edible mushroom exploitation.

The expansion in commercial harvesting in some countries and international trade has led to an increase of harvesting pressure and concerns about overharvesting and damage to fungal resources (Boa 2004). Some countries or regions have introduced legal restrictions on the harvesting of edible fungi in natural habitats because they fear that the removal of fruit bodies from the forest, often before spore dispersal, might impair their reproduction. However, experimental studies on the effect of harvesting have revealed that long-term and systematic harvesting reduces neither the future yields of fruit bodies nor the species richness of wild forest fungi, irrespective of whether the harvesting technique was picking or cutting (Egli *et al.* 2006; Norvell 1995; Pilz *et al.* 2003). However, after mass removal of fruit bodies, on a local fine scale establishment of new mycelia may be slower due to competition with other fungi, because local mass spore deposition from fruit bodies may compensate for the low probability that a single spore will germinate and establish a new mycelium (Heegaard *et al.* 2016).

Albeit poisonous mushrooms only represent a very small fraction of all wild mushrooms, some of them are deadly poisonous, and ingestion of those may result in serious intoxication, including death. The death cap (*Amanita phalloides*) and related Amatoxin-containing *Amanita* species cause deadly intoxication worldwide every year. In Poland, for example, 54 persons died between 1953–1962 as a consequence of the consumption of *A. phalloides* (Grzymala 1965). Some countries have established information/consulting services, giving the opportunity to private mushroom harvesters to present their harvests to trained mushroom advisers sorting out the poisonous mushrooms. Such services exist for example in Finland, in Norway ('svamp police'), in Italy or in Switzerland where a network of about 300 mushroom checkpoints all over Switzerland exists.

CASE 6.1: *The most appreciated mushrooms and truffles species in Europe*

There is a huge variability of mushroom preferences within European countries, and even between regions in the same country. Based on the work of Peintner *et al.* (2013) that lists the edible mushrooms authorized for trade in 27 European countries, we may consider the most relevant mushrooms and truffles, which are authorized in at least 7 countries. The list includes 27 genera with a total of 59 species:

Figure 6.1: *Marketed mushroom species. From left to right: Cantharellus cibarius (Photo credit: Željko Zgrablić), Boletus edulis (Photo credit: Irmgard Krisai-Greilhuber), Lactarius deliciosus (Photo credit: Friedrich Reinwald), Tuber aestivum (Photo credit: Irmgard Krisai-Greilhuber), Tuber melanosporum (Photo credit: Daniel Oliach).*

Agaricus arvensis, A. bisporus, A. bitorquis, A. campestris, A. silvaticus, A. silvicola, Cyclocybe cylindracea, Amanita caesarea, Armillaria mellea, Auricularia ssp., *Boletus aereus, Imleria badius, B. edulis, B. pinophilus, B. reticulatus, Calocybe gambosa, Calvatia gigantea, Cantharellus cibarius, Coprinus comatus, Cortinarius caperatus, Craterellus cornucopioides, C. lutescens, C. tubaeformis, Hydnum repandum, H. rufescens, Kuehneromyces mutabilis, Lactarius deliciosus, L. deterrimus, L. salmonicolor, L. sanguifluus, L. semisanguifluus, L. volemus, Leccinum aurantiacum, L. scabrum, L. versipelle, Lentinula edodes, Lepista nuda, Macrolepiota procera, Marasmius oreades, Morchella conica, M. elata, M. esculenta, M. gigas, Pleurotus cornucopiae, P. eryngii, P. ostreatus, Russula cyanoxantha, R. vesca, R. virescens, Suillus granulatus, S. grevillei, S. luteus, S. variegatus, Tricholoma portentosum, Tuber aestivum, T. brumale, T. magnatum, T. melanosporum, Xerocomus subtomentosus.*

CASE 6.2: *Mushrooms also cause poisonings*

The Public National Poisons Information Centres provide an advisory service in case of suspected poisonings. The Swiss National Poisons Information Centre, Tox Info Suisse, for example, registered since its establishment in 1966 over 12,000 mushroom-related calls (Schenk-Jäger *et al*. 2016). Despite the highly developed and effective mushroom control system in Switzerland, 32 mushroom-related *A. phalloides* – or amatoxin-intoxications by related species were registered from 1995-2009, 5 of them with fatal outcome (Schenk-Jäger *et al*. 2012).

Between 2010 and 2015 in Munich, the Giftnotruf München registered 2661 cases of real and/or assumed mushroom intoxications. They can be subdivided in 56 cases of abuse (intentional consumption), 25 commercial accidents, 2255 household accidents, 11 suicide attempts and 314 others (Bettina Haberl and Rudi Pfab, unpubl. pers. comm.).

According to Arif *et al.* (2016) in Austria in 19 years (1996-2014) the Poison Information Centre had 1,072 inquiries regarding mushroom ingestion in children (1-14 years old). In 68%, fungal parts were ingested raw (within these cases *Amanita phalloides* was verified in 1.6%). In 32% of the cases, mushrooms were consumed cooked and *Amanita phalloides* was verified in 3.5% of these cases. Three children developed serious symptoms (2 cases to liver transplantation, one child deceased). In 2016, the mushroom counselling service of the municipality of Vienna altogether gave advice 401 times, with 2 samples of deadly poisonous, 30 poisonous, 132 inedible, and 237 edible species.

Even nowadays new, unusual fatal mushroom poisonings occur which are due to hitherto unnoticed toxic species. For instance, it is not well known that sometimes morels can cause neurological symptoms similar to drunkenness (one case in Austria in spring 2016). *Echinoderma aspera* may cause alcohol abuse syndromes; *Russula subnigricans* caused fatal rhabdomyolysis in Japan while in China the "Yunnan Sudden Unexplained Death-Syndrome" generated by *Trogia venenata* caused hundreds of deaths. Further toxic species are *Pleurocybella porrigens*, *Scleroderma* spp., *Omphalotus olearius* and *Clitocybe amoenolens*, which recently have also been found in Central Europe. A very dangerous and new phenomenon is confusion of highly valued medicinal fungi with toxic ones, e.g. *Ganoderma lucidum* with *Ganoderma neojaponicum* or with *Podostroma cornu–damae*, the latter is by far the most poisonous mushroom existing (Berndt 2016).

Figure 6.2: *Potential confusion within fungal species. Russula heterophylla (left) is an edible species while Amanita phalloides (right) is poisonous (Photo credit: Irmgard Krisai-Greilhuber). Amanita verna, commonly known as the fool's mushroom, is a deadly poisonous basidiomycete, one of many in the genus Amanita (Photo credit: Simon Egli).*

Fungi are more and more recognized internationally as organisms which are in need of concern for conservation measures, especially habitat protection, as is the case with animals and plants. Several international societies were founded dealing with conservation of fungi. For instance, the International Society for Fungal Conservation (ISFC) promotes conservation of fungi globally (http://www.fungal-conservation.org/). On their homepage it is stated that one of the main aims is to be a Global Federation for Fungal Conservation Groups, supporting regional or national and local bodies in fungal conservation activities.

The Global Fungal Red List Initiative (http://iucn.ekoo.se/en/iucn/welcome) was started and finally led to the inclusion of fungi in the IUCN Red List of Threatened Species. There are Red Lists in many European countries either on a local or national scale, e.g. Switzerland (Senn-Irlet *et al.* 2007), Czech Republic (Holec and Beran 2006), Poland (Wojewoda and Lawrynowicz 2004), the Netherlands (Arnolds and Veerkamp 2008), Sweden (Gärdenfors 2005), Germany (Bundesamt für Naturschutz 2017), or Austria (Dämon and Krisai-Greilhuber 2017). In Europe finally in 2013 the Bern Convention (Council of Europe) has created a Charter for Fungi-Gathering and Biodiversity (Brainerd and Doornbos 2013), see Union for the Conservation of Nature (www.iucn.org); which also includes a Code of Conduct for mushroom picking in nature.

This chapter will provide a characterisation of fungal communities and the different approaches to study fruit body production (chapter 6.2). The ecology of mushroom and truffle species is introduced in chapter 6.3 and the necessary requirements for a fungal oriented forest management are discussed in chapter 6.4. The role of trade as the main driver of the wild mushrooms economy and other socio-economic aspects are described in chapter 6.5.

6.2 *Characterization of fungal communities and fungal diversity*

The great temporal and spatial variation in mushroom and truffle yields between and within years (Alday *et al.* 2017) makes the fine characterization of fungal communities difficult. The study of the presence/emergence of mushrooms has been traditionally based on the collection of fruit bodies from permanent plots or transects, which are systematically sampled once per week (Bonet *et al.* 2012; Martínez de Aragón *et al.* 2007; Egli *et al.* 2006; Dahlberg 1991). This data are very valuable since, like any other forest resource, forest management plans demand first the estimation and evaluation of the marketable resources in quantifiable terms (Díaz-Balteiro *et al.* 2003; Palahí *et al.* 2009).

Despite the relevance of obtaining potential mushroom productions, an extensive sampling approach has to be conducted for several years if the final objective is to obtain representative data (Martínez de Aragón *et al.* 2007; Büntgen *et al.* 2013). This long-term sampling is followed together with measurement of the environmental characteristics of the plots, especially to understand the causal factors affecting mushroom production (Vogt *et al.* 1992). Similarly, the sampling scheme will depend on the previously established objectives. For instance, measuring fruit body species richness requires as large sampling plots or as long transects as possible (Martínez de Aragón *et al.* 2007), whereas the use of smaller sampling plots or transects (100 m^2) is advisable if the aim is to estimate fruit body productivity (Dighton *et al.* 1986; Hintikka 1988; Smith *et al.* 2002; Martínez de Aragón *et al.* 2007). Due to the high sampling frequency in these plots, caution is advised with the use of heavy equipment or any other factors such as trampling of the forest floor causing soil disturbance, which can negatively affect mushroom production (Wästerlund 1989; Egli *et al.* 2006). In addition, any silvicultural treatment, such as thinning, also needs to be taken into account, since it has been shown that forest management has an effect on the mushroom production and diversity (Bonet *et al.* 2012; de-Miguel *et al.* 2014, Egli *et al.* 2010, Tomao *et al.*, 2019). Finally, to avoid losing data, temporal organization of samplings will be important, e.g. sampling at the end of week in order to reduce the probability of mushroom hunting by other pickers (Martínez de Aragón *et al.* 2007). In addition, if the objective is the use of a non-destructive sampling approach (i.e. fruit bodies are only counted *in situ*), fruit bodies might be marked with a colour stain to avoid double counting one week later (Egli *et al.* 2006).

If the sampling approach is based on fruit body counts and weight measurement, samples are brought to the laboratory after sampling for fresh weight measurement and fruit body count (Martínez de Aragón *et al.* 2007). Moreover, since fresh weight is biased by the actual weather conditions determining the water content of the fruit body, fruit bodies should be dried in air-vented oven at 35-40 °C and weighed (Väre *et al.* 1996). A classification of the mushrooms is necessary, especially if we are focused in understanding their commercial status (e.g. edible non-marketed, marketed) together with the measurement of all of the environmental factors of the plot, which will be later used to design the forest management plans to optimize mushroom production, according to any specific tree species (Martínez-Peña *et al.* 2012).

Despite the need of conducting fruit body samplings for future commercial purposes but also to better understand the ecology of these species, the current methodology used to estimate fungal productivity is very limited when it comes to hypogeous species such as truffles, or ephemeral species with a very short lifespan of their fruit bodies, as well as species which fruit very rarely and not every year (Vogt *et al.* 1992). In addition, due to the high costs associated with these sampling approaches, there is a need to improve the tools to detect and quantify mushroom yields. In the next subchapters, we will present some new promising approaches that may help estimating or predicting the mushroom production and approximate its diversity both at ground level but also belowground by using molecular genetic techniques.

6.2.1 The use of belowground communities to study fruit body production

Fruit body-forming fungi in forest soils are supported by a vegetative system which involves two main structures; the fungal mycelia and the mycorrhizas. However, these structures have been very difficult to study, since fungal species living in soil are highly diverse (Buée *et al.* 2009) and, in the case of fungal mycelia, it is often not visible to the human eye. The use of novel molecular techniques to study fungal communities living belowground has answered several ecological questions such as seasonality of soil mycelia (De la Varga *et al.* 2012; Jumpponen *et al.* 2010) and is allowing the identification of the fungal species living in soils (Nilsson *et al.* 2006; 2012; 2013). Other techniques such as qPCR have also been developed with the aim to quantify the specific fungal species living in soils, e.g. *Lactarius vinosus* (Castaño *et al.* 2016), *Boletus edulis* (De la Varga *et al.* 2013) and *Tuber melanosporum* (Liu *et al.* 2014; Parladé *et al.* 2013; Suz *et al.* 2006). The use of soil mycelia (also referred as extramatrical mycelia) has the advantage with respect to fruit bodies that it is much more stable across years, within the year, has much higher diversity (Buée *et al.* 2009) and shows many other species not forming or only forming inconspicuous fruit bodies. However, molecular genetic methods need to be improved and need to circumvent current biases and errors, so we can to differentiate between productive viable mycelia and other fungal DNA sources, such as propagules, very young mycelia, inactive or dead mycelia (Simmel 2016 a, b; Bässler *et al.* 2016). A first step to overcome these problems is the use of metranscriptomics, which could provide information about the active fungal community operating in forest soils.

It is apparent that the fungal community shows much higher diversity below-ground (mycorrhizas and mycelia) than aboveground evidence (fruit bodies) (Dahlberg *et al.* 1997; Gardes and Bruns 1996; Koide *et al.* 2005), but community studies focused on understanding more specifically to what extent the soil fungal mycelia can predict or estimate the potential mushroom production are missing. Thus, to date only few examples report correlations between fungal mycelia (Suz *et al.* 2008; Liu *et al.* 2016) or mycorrhizas (De la Varga *et al.* 2012; Parladé *et al.* 2007) and their fruit body production. Therefore, it is needed to understand if there is such relationship, and if this may depend on the fungal species or the spatial scale considered, as well as whether they may be affected by the seasonality of the fungal mycelia (De la Varga *et al.* 2013) or the sampling design (e.g. plot size) (Martínez de Aragón *et al.* 2007). The potential use of soil samples or mycorrhizas to estimate mushroom production will be hopefully soon clarified once all the methodological questions are clarified and biases and errors coming from the use of high-throughput DNA sequencing techniques are solved.

6.2.2 The use of spore traps to study fruit body production

Fungal spores or fungal propagules could be also used to estimate potential fruit body production as an alternative to the use of mycorrhizas of fungal mycelia, yet no evidence of the feasibility of this approach has been presented so far. However, despite few, recent studies have provided new insights in such relationship (see discussion in Peay and Bruns 2014) and there is also new evidence that it is possible to detect fruit body emergence using spore traps together with molecular genetic techniques (Castaño *et al.* 2017, 2019).

The use of spore traps to detect and quantify fungal spores and use such data as a proxy for the colonization potential of fungal inoculum has been mostly restricted to plant pathology (Jackson and Bayliss 2011). Literature in this field has provided evidence that the use of spore trap samples with molecular techniques (e.g. quantification of the spore innoculum by qPCR) is useful to quantify the spore inocula of specific fungal pathogens such as *Fusarium circinatum* (Schweigkofler and Garbelotto 2004) or *Hymenoscyphus fraxineus* (Chandelier *et al.* 2014). An important aspect concerning the use of these spore traps is that they should be easy to handle and easy to replace, since they will be most likely located in forests, where accessibility is not always easy. In this sense, both passive funnel and filter traps were shown to have fungal spores (Chandelier *et al.* 2014; Peay and Bruns 2014) (see Figure 6.3), which are most likely derived from the biological activity of these organisms nearby. One of the disadvantages of using these devices is that sporulation is very species-specific in terms of the quantity of released spores and many basidiomycetes (especially ectomycorrhizal) seem to disperse less abundantly and dispersal is often restricted to a very short period in the year (Galante *et al.* 2011; Kivlin *et al.* 2014; Li 2005). Furthermore, the traditional identification approaches, e.g. microscopy techniques, are almost prohibitive under this context and would be very time-consuming (West *et al.* 2008). Here, the use of high-throughput DNA sequencing represents another promising opportunity to characterize these communities. Again, apart from the technical considerations when using molecular techniques (see a review in Lindahl *et al.* 2013), other factors such as precipitation events, wind direction or specific traits (Oliveira *et al.* 2009; Burch and Levetin 2002; Troutt and Levetin 2001; di Giorgio *et al.* 1996) will most likely affect any hypothetical relationship between spores and fruit body yields and therefore should be studied and taken in account in future.

Figure 6.3: *Example of a passive spore traps or funnel spore trap (Left) and an active (Burkard) spore trap (Right) using a solar panel as a source of energy supply (Photo credits: Carles Castaño).*

6.3 Ecology of mushroom and truffle species

Fungi exhibit a high variability in their nutrition approaches and the related ecology. Pathogenic fungi feed on the hosts that they attack, usually causing tree diseases and potential landscape-level disturbances in forests. Not many pathogenic fungi are considered commercial as opposed to saprotrophic or mycorrhizal fungi. As degraders of the recalcitrant organic matter needed for nutrient cycling and the forest soil development, many mushroom-forming saprotrophic fungi are easily cultivated and sold. Frequently cultivated genera are *Agaricus*, *Pleurotus*, *Ganoderma*, *Volvariella* and *Lentinus*. The cultivated mushrooms are not regarded as wild mushrooms. Among commonly recognized non-wood forest products (e.g. wild edible mushrooms) we consider in this context only species and genera that grow in ectomycorrhizal symbiosis with living trees and shrubs or are saprotrophic species in natural habitats.

6.3.1 Distribution patterns and productivity

A wide range of biotic and abiotic factors influences fruit body productivity. These factors are commonly classified into three main groups: (a) meteorological variables, e.g., precipitation, temperature (Alonso Ponce *et al.* 2011; Wollan *et al.* 2008); (b) local site characteristics, e.g., soil, altitude, slope aspect (de-Miguel *et al.* 2014; Bonet *et al.* 2004); (c) forest stand structure, e.g., tree species, stand density, stand age (Bonet *et al.* 2008; North and Greenberg 1998). This subchapter will describe the main ecological factors affecting the presence of mushrooms and truffles, focusing on target species such as *Boletus edulis*, *Lactarius* spp. and *Tuber* spp. (see management of such species in chapter 6.4).

Precipitation and temperature are the main ecological factors affecting fungal distribution and fruit body production on a global scale (Sato *et al.* 2012; Straatsma *et al.* 2001; Wardle and Lindhal 2014; Wollan *et al.* 2008). Fungal yields vary strongly between years (Alday *et al.* 2017), depending on water availability and temperature, but these factors alone do not explain the whole extent of this variation (Egli 2011). Thus, increased precipitation directly causes the fungal yield to increase (Heegaard *et al.* 2016), but conditioned by other variables such as wind or temperature. Temperature is another crucial variable that determines the start of fruit body production during yearly cycles (Wollan *et al.* 2008). Certain fungal species, as the widely appreciated *Amanita caesarea* and *Boletus aereus*, are thermophilic and thus their distribution is restricted to warmer habitats of southern and central Europe (Breitenbach and Kränzlin 1995; Papetti *et al.* 2011).

Even for fungal species that show cosmopolitan distribution patterns, soil properties are often a crucial factor that influences fruit body production. The *Boletus edulis* group is distributed worldwide (Águeda *et al.* 2006; Hall *et al.* 1998a) but in certain habitats, specific ecological conditions are required. In

Cistus ladanifer shrublands in Spain, fruit bodies from this group are produced only in strongly acidic soils with very narrow textural range (Alonso Ponce *et al.* 2011). *Tuber magnatum* is another example of a species whose occurrence is also linked with specific soil conditions, as described by Bragato *et al.* (2004; 2010) in Istria (Croatia), and by Hall *et al.* (1988b). *Tuber melanosporum* is limited to alkaline soils (pH 7.5-8.5; Colinas *et al.* 2007), while *Tuber aestivum* is adapted to a broader range of ecological conditions, and can be found in almost every European country (Stobbe *et al.* 2013). A result from Bonet *et al.* (2004) and more recently by de-Miguel *et al.* (2014) in the Spanish Pyrenees suggests that slope, aspect and geographic exposition are a significant factor for fungal yield: northern aspects are found to be more productive for some fungal species in respect to southern, drier aspects. Fungal productivity varies along a range of altitudes. Depending on the latitude, we may observe a variation of fungal yields in altitudes that also relates with climatic conditions. The general trend is an increase of mushroom collection once we increase the altitude with a usual decrease at higher altitudes associated with low temperatures (Jang and Kim 2015; de-Miguel *et al.* 2014). In general, we may confirm that fungi are distributed over a wide range of altitudes, mostly depending on geographical position.

Numerous ectomycorrhizal fungi are species-specific towards host trees. Distribution of such species is often limited by the distribution of the corresponding host plants. As an example, *Lactarius deliciosus* group is mycorrhizal with *Pinus* sp. (Consiglio and Papetti 2009; Heilmann-Clausen 2000) and its distribution coincides with the host tree distribution. In contrast, *Boletus edulis* group species and *Cantharellus cibarius* have a broader association (Danell 1994; Hall *et al.* 1998a; Knudsen and Vesterholt 2012), linked with broadleaved and coniferous host trees. Stand density can affect ectomycorrhizal fruit body production in natural and managed conditions (Tomao *et al.* 2017). *Tuber melanosporum* requires low density habitats while *T. magnatum* and *T. aestivum* fruits in stands with full canopy closure. Fungal species often follow different stages of forest succession, showing preferences towards either young, mature or old forest stands (North and Greenberg 1998). Some species fruit regularly in all forest types in respect to age classes, as Bonet *et al.* (2004) outline for the *Lactarius deliciosus* group.

6.3.2 Impact of global change on diversity, productivity and distribution patterns

The current awareness of the global environmental trends and climate change scenarios has finally reached the political ranks, due to the growing concerns on our ability to contain the decline of life-supporting resources (Rockström *et al.* 2009). According to the European Environmental Agency (EEA), both climate change and human activity are major drivers of losses in European natural resources such as biodiversity, soil, water and land (EEA 2015). In order to understand the real costs linked to such losses, integrating economic tools for the evaluation of ecosystem services, such as those developed by TEEB (TEEB 2017), is essential. They should help policy makers decide for the conservation of NWFP such as mushrooms, both in the management of human activity and in adaptation to climate change (Pedrono *et al.* 2016; Schulp *et al.* 2014).

Mushroom productivity can be affected by climate change at two levels: more immediately, through phenological shifts; and ultimately, through habitat replacement. The former can be assessed through contemporary and retrospective studies, and several reports have provided compelling evidence of such shifts (see review of Boddy *et al.* 2014). Thus, the comparison with historical records has revealed, for the summer-autumn fruiting season, a significant increase of its duration for many mushroom species (but not for all), with an average fruiting time later in the year, correlated with a delay in frosting and thus an extended vegetation season (Gange *et al.* 2007; Kauserud *et al.* 2012; Andrew *et al.* 2017). Due to the dependence of fungi on vegetation resources, it seems clear that climate warming affects mushroom phenologies indirectly (Sato *et al.* 2012; Kauserud *et al.* 2012; Gange *et al.* 2013), but climate warming may also drive a concomitant increase in mushroom productivity directly, especially for saprobic species (Büntgen *et al.* 2013). A similar study for spring-fruiting species indicated a slight tendency for earlier fruiting, correlated with elevated temperatures in winter and the earlier onset of spring (Kauserud *et al.* 2010). Due to land use changes and climate change a considerable shift in species composition over time may also take place, as e.g. seen in the studies of Simmel (2016b) and Stulik (2016) where species numbers were quite similar but species composition had changed over time, resulting in a loss of rare and red listed species and an uprise of ubiquitous species. Such shifts, while overshadowed in the shorter term by the unpredictability of meteorological patterns related to phenomena such as the North Atlantic Oscillation (CPC 2017), spell a progressive change in the management and utilization of forest resources (de-Miguel *et al.* 2014). Thus, short-term policy responses should be directed at the mitigation of climate impacts, which is much wiser than staying inactive and hoping for the best (Pedrono *et al.* 2016).

Modelling species distributions (Hijmans and Elith 2016) according to relevant environmental variables provides potential geographical distributions for each species, and examples of this approach for mushrooms have highlighted the role of temperature in the present (Wollan *et al.* 2008) and determined potential refugia in the past (Sánchez-Ramírez *et al.* 2015). Future geographical displacements of species due to climate change can also be predicted with this approach, under current assumptions of climate trends, with compelling, albeit speculative, results. Thus, one simulation of the potential forest cover in Europe predicts that, by 2070–2100, most of France will not be fit for central European oaks or beech, but rather for Mediterranean oaks, and Germany will lose Norway spruce and Scots pine, just to name two examples (Hanewinkel *et al.* 2013). The economic losses calculated for Europe in that study refer to wood production, but similar efforts could be undertaken (in spite of all uncertainties) for mushrooms and other NWFP: on one hand, to estimate the impacts of habitat replacement (negative as well as positive) and the costs of transition, and on the other, to assess the consequences of abandonment of forest-based economic activities.

One obvious outcome of such long-term predictions is to prompt the question of what can be done today, given the relatively slow responses by forest ecosystems, to ensure an efficient transition in forest cover — and, with it, of mushroom production. The installation of prospectively more adapted forests must rely not only on climate and soil characteristics, but also on the below-ground connectivity with other ectomycorrhizal hosts (Perry *et al.* 1990; Büntgen and Egli 2014; Tubay *et al.* 2015; Lavorel *et al.* 2015). Once settled, such new plantations have a good prospect for maintaining soil health and mushroom diversity (Oria-de-Rueda *et al.* 2010). However, in spite of the overall good scores by European countries, regarding the ND-GAIN index (ND-GAIN 2017), one study has detected a lack of attention, in the European policies for adaptation to climate change, to species interactions (van Teeffelen *et al.* 2014).

6.4 Towards mycosilviculture: fungal oriented forest management and planning

The increasing importance of the edible mushrooms and truffles in the local and global markets is also increasing the interest toward suitable ways of managing and enhancing mushroom yields in forest ecosystems (Pilz and Molina 2002). Contrary to the so-called 'direct' NWFP, which are obtained directly from a particular tree species (e.g., tree fruits, cork), mushrooms are typically considered as indirect wild forest products that coexist with trees and whose provision is modulated by an array of site and stand conditions. Such 'indirect' wild forest products have been usually considered as side-products of a given silvicultural regime and not part of a predefined production goal within the framework of traditional timber-oriented forestry. Since forest fungi are tightly connected to the main element that characterize forest ecosystems (i.e., the trees), forest management and silvicultural operations are likely to influence fungal and mushroom dynamics (Egli 2011).

Silviculture has been defined as the array of treatments that may be applied to forest stands to maintain and enhance their utility for any purpose (Smith 1986), including benefits derived either directly or indirectly from the trees themselves, other plants, water, wildlife and minerals found in forested areas (Nyland 2002). Therefore, silviculture has been always regarded as the instrument for managers to retrieve multiple ecosystem services from forest systems. Within this context, mycosilviculture may be defined as the array of silvicultural treatments and operations aiming at enhancing the provision of mushrooms and truffles in order to integrate these products into multifunctional forest management planning. Indeed, previous research has shown that mushrooms can result in higher economic profit than timber in Mediterranean areas characterized by a reduced profitability of timber harvesting (Palahí *et al.* 2009), and can also represent a considerable proportion of the whole forest value even in regions where timber-oriented forestry is profitable (Tahvanainen *et al.* 2016).

Although weather and site conditions highly determine the occurrence and productivity of mushrooms and truffles in forests and agroforestry systems (see chapter 6.2), only those variables related to the stand structure and composition can be modified through mycosilvicultural operations in order to propose fungal-oriented management recommendations in large-scale forested landscapes. An exception to this are the intensively managed, cultivated systems for truffle production where irrigation may constitute an additional management tool, therefore modifying the micro-site moisture conditions. Thus, managers and landowners can mainly affect certain ecosystem attributes such as stand age, stand density, tree species composition and forest cover (Tomao *et al.* 2017). Accordingly, the modification of the rotation length, stand basal area or tree species composition through forest management is expected to have an impact on fungal dynamics. Similarly, differences in fungal productivity may arise from applying either even-aged or uneven-aged forest management methods. In addition, the degree of mechanization and associated soil disturbance from timber thinning and harvesting operations may have an impact on the amount of mushrooms produced in a given forest area (see chapter 4.3).

A set of silvicultural procedures covering, among other operations, tending, thinning, pruning, harvesting and re-establishment of forest stands is referred to as a silvicultural system, which can be conducted on a continuum of forest management intensity ranging from extensive to intensive management schedules (Duncker *et al.* 2012): from rather passive systems such as unmanaged forests or nature reserves, through semi-natural systems of medium management intensity, to intensively managed cultivated agroforestry systems (Table 6.1). However, the observed pattern of occurrence of mushrooms in a certain forest ecosystem for total, edible and/or marketed productions may not be the same for individual target species since fungal species have different ecological strategies. Thus, the literature reflects very contradictory effects of silvicultural treatments on the individual species (e.g., Kardell and Eriksson 1987; Ohenoja 1988; Shubin 1988; Kropp and Albee 1996; Kranabetter and Kroeger 2001; Egli *et al.* 2010, Bonet *et al.* 2012). Additionally, most of the studies are very local or regional, and consequently between-region differences in terms of site characteristics, weather and forest structure prevent adopting general recommendations, and further in-depth analysis focusing on individual fungal species is recommended. Furthermore, the large amount of potential variables related to mushroom productivity and their interdependence makes it difficult to give clear recommendations for managing mushroom yields. Since both positive and negative effects of silvicultural operations on mushroom yield are theoretically possible, the main dilemma when considering mushroom and truffle production within the framework of mycosilviculture may be summarized as follows: i) how can silvicultural treatments enhance the provision of edible fungi, and ii) how can silvicultural guidelines be modified and adapted to increase the production of target fungal species.

Table 6.1: Silvicultural systems associated to typical forest types producing mushrooms or truffles. Management intensity refers to the periodicity of the interventions.

Forest type	Silvicultural regime	Silvicultural operations	Management intensity
Natural	Unmanaged forest / reserve	Isolated interventions	Passive
Semi-natural	Continuous cover forestry	Selective cuttings, thinning from above	Low – Medium
Semi-natural	Even-aged forestry	Shelterwood methods, thinning from below	Medium
Plantation	Intensive even-aged forestry	Final felling, replanting, thinning from below, pruning	High
Plantation	Agroforestry / cultivation	Final felling, planting, fertiliza-tion, weed and shrub control, irrigation	Intensive

6.4.1 *Silvicultural treatments and their impact on mushroom yields*

Silvicultural operations can affect the occurrence, productivity and reproduction of mushrooms. Understanding the ecology of ectomycorrhizal fungi and the effect of forest management practices such as forest thinning, pruning, shrub and weed control or regeneration methods may contribute to improving natural mushroom production in forest ecosystems. In this chapter, we review the current state of the art of forest management practices that can contribute to enhancing mushrooms and truffles productivity and evaluate the potential of mycosilviculture.

6.4.1.1 *Thinning*

Forest thinning aims to manage the competition among trees by removing some individuals in order to favour the growth of the remaining trees. After tree removal, the remaining trees can increase their photosynthetic activity and allocate more carbohydrates to their root system, which benefits mycorrhizal fungal species. Other factors such as microclimatic changes in the soil layer and soil disturbance arising from forestry operations may also affect both productivity and composition of fungal species (Bonet *et al.* 2012).

While some studies have reported higher mushroom productivity in thinned stands (Kirsi and Oinonen 1981; Shubin 1988; Ohenoja 1988; Egli *et al.* 2010; Bonet *et al.* 2012), other authors have not found such trends (Kardell and Eriksson 1987). A remarkable post-thinning increase in diversity and productivity of mycorrhizal fungi has been reported by Egli *et al.* (2010) in a Swiss forest, and Bonet *et al.* (2012) found an immediate positive effect of thinning on the yield of *Lactarius* group *delicious* (Figure 6.4). Similarly, thinning of *Cistus ladanifer* scrublands can enhance the production of some valuable species such as *Boletus edulis*, *Leccinum corsicum* or *Lyophyllum decastes* (Hernández-Rodríguez *et al.* 2015). On the other hand, other studies have observed an initial negative thinning reaction on mushroom yield with a subsequent recovery of the productivity after 3 to 6 years (Pilz *et al.* 2006; Egli *et al.* 2010). This apparent contradiction may probably arise from differences in soil disturbance caused by forest harvesting operations, which was minimal, in the experiment conducted by Bonet *et al.* (2012). Therefore, low-impact timber harvesting procedures (i.e., with limited soil disturbance and compaction associated to mechanization of forestry works) may also contribute to diminishing potential negative impacts of thinning operations on mushroom yields and/or to further enhancing any positive thinning effects on fungal fructification.

Thinning intensity also seems to affect the subsequent production of mushrooms. In this regard, light to moderate thinning seems to enhance the productivity of certain mushrooms, including important marketable species such as the *Lactarius deliciosus* group, whereas heavy thinning seems to reduce the fruiting of target fungal species (Bonet *et al.* 2012).

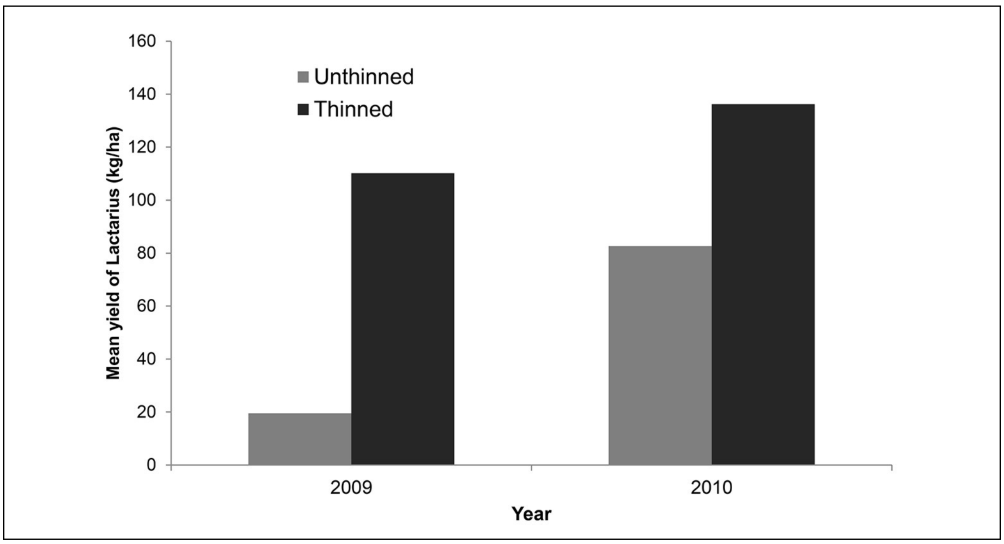

Figure 6.4: *Immediate effect of thinning on Lactarius deliciosus group yield in North-Eastern Iberian Peninsula. Thinning treatments were conducted in August 2009, right before the start of the autumn season, when Lactarius sp. fruits (Bonet et al. 2012).*

6.4.1.2 Regeneration methods

The main regeneration methods may be summarized in the following concepts: clearcutting, shelterwood methods and selective cutting. Clearcuts and shelterwood methods are typical of even-aged forestry, sometimes characterized by thinnings during the rotation period and final fellings at the end of the rotation, which implies the removal of tree cover. Although shelterwood methods may be also regarded as transient states toward uneven-aged forestry, selective cutting is the typical regeneration method (that also comprises tending, thinning and final cutting) in continuous cover forestry, where tree cover is always maintained. Differences in colonization strategies, use of the available water and nutrients, and competitive abilities of different fungi contribute to explaining that, generally, the number of fungal species increases with stand age with a peak around canopy closure of the forest stand and the fungal community composition stabilizes at the stand reinitiation stage (Dahlberg 2001; Twieg *et al.* 2007). Some fungi are able to rapidly colonize a site after disturbance by spores or resistant propagules, whereas others need an intact mycorrhizal network that connects them to another tree for colonization. After operations such as clearcuts, these patterns are most pronounced when no stumps and living roots from which mycorrhizal fungi could recolonize new roots are left over (Peter *et al.* 2013). Thus, negative effects of clearcutting on mushroom productivity (at least on the productivity of mycorrhizal fungi) have been reported in previous research (Kardell and Eriksson 1987; Ohenoja 1988). However, the potential inoculum in the soil of a clearcut area may be rather similar to the adjacent forest area (Harvey *et al.* 1980; Dahlberg and Stenstrom 1991; Le Tacon 1997). At the development stage of young regenerated stands, mushroom productivity has been found to be recovered (Hintikka 1988). When vigorous adult trees are left in the stand, as in the case of shelterwood or retention tree methods (which may be also regarded as high intensity forest thinning), the mycorrhizal fungal diversity is much higher than in clearcut stands (Peter *et al.* 2013), since the remnant trees act as fungal reservoirs allowing fungi to colonize the new offspring. Similar observations were made after windthrow, that should be considered as a natural clearcut. Ten years after a heavy windthrow event, the number of infective ectomycorrhizal fungi was significantly reduced, but the soil still contained enough mycorrhizal fungi to fully colonize ongrowing seedlings, even 10 years after the event (Egli *et al.* 2002).

In general, in an even-aged forestry framework, the integration of mushroom production into forest management planning will result in longer rotation lengths so that the forest cover allows for mushroom production over a longer period (Palahí *et al.* 2009; Bonet *et al.* 2012). In this regard, selective cutting of different intensities within the framework of continuous cover forestry may avoid temporal gaps without mushroom production inasmuch as the forest cover (of host trees) remains over time (de-Miguel *et al.* 2014).

6.4.1.3 *Pruning*

In principle, pruning may have an impact on mushroom productivity if the removal of living branches affects significantly the overall photosynthetic activity of the tree, which may further affect the allocation of carbohydrates to the root system and mycorrhizal fungi. However, such an assumption is just based on theoretical considerations, since no experiments have been carried out so far. In this regard, the only group of fungi for which pruning of host trees is recommended is represented by the genus *Tuber* in cultivated and intensively managed agroforestry systems, being the main tree hosts *Quercus sp.* and *Corylus avellana*. Thus, during the first years after plantation establishment, pruning is carried out primarily for correcting structural defects of the host trees (Sourzat 2002) and favouring the desirable tree form associated with suitable conditions for truffle fructification (Ricard 2003). Such formation pruning or early training aims at attaining a tree crown with the shape of an oval or an inverted cone by eliminating lower branches and basal sprouts. Formation pruning may begin in the third year depending on the vigour of the plant and should be of low intensity (Bonet *et al.* 2009). This pruning procedure may influence positively *Tuber*, aiming at increasing the amount of light that reaches the ground providing additional space for installing irrigation systems, which may further increase both truffle productivity and the efficiency of truffle collection in the future (Reyna 2012).

6.4.1.4 *Weed and shrub control*

Weed and shrub control is only considered as a normal practice in intensively managed truffle plantations or agroforestry systems. During the first 2 to 4 years after plantation establishment, the area around each tree should be kept free of weeds by using manual hoes (Bonet *et al.* 2009) or mulches (Olivera *et al.* 2014b). This is supposed to increase the survival rate of the host trees by eliminating competition for water and nutrients while increasing the proliferation of mycelium. In the rows between each tree, the land should be cultivated with suitable tools allowing shallow treatments reaching a soil depth not greater than 15 to 20 cm (Reyna 2012). Once the typical ‘burnt’ area provoked by the truffle’s allelopathic activity appears, some landowners further suppress weed development by means of mechanical tools, i.e., with depth-control tines reaching a soil depth not greater than 10 cm, which also contributes to soil aeration.

6.4.1.5 *Fertilization*

Previous research has observed a positive effect of sporadic fertilization on mushroom dynamics (Hora 1959; Kutafyeva 1975), although other studies have reported a decrease in mycorrhizal productivity and diversity in the third or fourth year after the continuous application of fertilizers (Termorshuizen 1993; Ohenoja 1989; Cox *et al.* 2010; Lilleskov *et al.* 2011). Since ectomycorrhizal symbiosis is generally regarded as an adaptation to conditions of nitrogen (N) scarcity, when N availability increases, trees allocate less carbon to the roots and mycorrhizal symbionts, and more to the aboveground biomass (Peter *et al.* 2013). Based on these assumptions, fertilization of black truffle plantations has been recommended only if the soil has an exceptionally low concentration of a particular nutrient in order to compensate for such deficit (Olivier *et al.* 2012). However, a common practice in areas with acidic soils is to gradually add slow-release calcareous corrections with $CaCO_3$ before cultivating the land. It is worth highlighting that these procedures are generally carried out in intensively managed systems and not in natural forest stands.

6.4.1.6 Irrigation

Irrigation is not a common practice in forest stands, although a positive effect on mushroom yield might be expected (e.g. Wiklund *et al.* 1995; Sarjala *et al.* 2005). In black truffle plantations, regular watering is recommended during the first years until the root system is well established and, later on, in the productive phase in order to stabilize the annual fluctuations in truffle yield caused by interannual changes in the meteorological conditions (Olivier *et al.* 2012). However, similar to the above-described effect of fertilization, excess of water could also cause a decrease in the amount of black truffle production (Bonet *et al.* 2006; Olivera *et al.* 2011). Recent studies (Olivera *et al.* 2014a) highlighted the need for introducing moderate irrigation doses in order to increase the presence of *Tuber melanosporum*. Accordingly, they recommend complementing natural precipitation up to 50% of the evapotranspiration during the first half of the growing season, and allowing for some slight water stress before the autumn rains.

6.4.1.7 Prescribed burning

As alternative to thinning, vegetation may be also managed by means of prescribed burning. Depending on the characteristics and intensity of a given burning prescription, a considerable post-fire increase in soil pH can occur, and negative impacts can be caused to upper roots and mycorrhizas (Certini 2005). This effect could be especially severe in the presence of great amounts of fuel load (i.e., vegetation biomass) as well as in the particular case that fire spreads slowly throughout the target area to be managed. This could even entail the total destruction of the rhizosphere system whose restoration could take many years. In a study on the short-term effects of wildfire on fungal communities in Mediterranean ecosystems in north-western Spain, dominated by *Pinus pinaster* and *Cistus ladanifer*, Martin-Pinto *et al.* (2006) found a decrease in total fungal dry weight in burned plots along with a significantly lower richness, and diversity of mycorrhizal species and lower production of edible fungi. However, although controlled burning needs to be applied with caution to avoid undesirable ecological and economic effects, some fire-prone pyrophytic or pioneer taxa of edible fungi such as the genus *Morchella* can be favoured immediately after fire events (e.g., Larson *et al.* 2016). Fernández de Ana (2000) also observed an increase in the production of *Tricholoma equestre*, *T. portentosum*, *Lactarius deliciosus* or chanterelles mushrooms after prescribed burning in *Pinus pinaster* forests of north-western Spain, using fire as management tool so that the tree root systems were maintained alive after the prescribed burning. The benefits of prescribed burning for promoting the yield of certain mushroom species may be more suitable in areas where the soil pH is very low since burning may not modify drastically the conditions of such acidic soils, especially if the fuel load is small. On the other hand, where the burning bush is thick and there is little fuel load, then the fire effect can be similar to a slashing, in the sense that no significant alterations in the ecosystem occur.

6.4.2 Important edible commercial wild forest mushrooms

Other than black truffle (*Tuber melanosporum*) yields, which have been the object of much research due to its high economic value and the progressive shift of its production from natural forests to cultivated agroforestry systems, the edible commercial fungal species most studied from a silvicultural perspective so far have been the *Boletus edulis* group and *Lactarius delicious* group. Cep or boletes (*Boletus edulis*) represent one of the most valuable and traded mushroom species worldwide, and *Lactarius deliciosus* group mushrooms are also highly appreciated in some countries and regions.

CASE 6.3: *Silvicultural recommendations for Boletus edulis production*

Martínez-Peña *et al.* (2012) reported that the optimal stand basal area that seems to maximize *B. edulis* production in *Pinus sylvestris* forests of central Spain is around 40-45 m2/ha (Figure 6.5). The influence of forest stand conditions was also observed in Italy, where Salerni and Perini (2004) found the greatest number of *B. edulis* fruit bodies in thinned stands with moderate thinning intensity, whereas very low production was found in the stands subjected to heavy thinning. The authors concluded that this species does not need a dense canopy in mixed forests (i.e., *Abies alba*, with a minor presence of *Picea abies*, *Pinus nigra* and *Acer monspessulanum* in that study), but an open and sunny habitat for maximizing their yields. The influence of clearing and the burning of the vegetation on *B. edulis* production in *Cistus ladanifer* scrubland ecosystems in Western Spain has been studied by Hernández-Rodríguez *et al.* (2015). *Cistus* scrublands are a source of highly appreciated boletes, which normally appear after a disturbance, namely clearing or fire. The authors observed that the production of *B. edulis* sporocarps is expected to start at about 5 years after treatment, whereas the maximum production, which can achieve more than 50 kg/ha/yr is reached at 14 years. According to this study, *B. edulis* production starts when the mean height of the scrubland reaches one metre, and achieves its maximum at a mean height of 1.5 metres. The highest production was associated with a shrub canopy cover of 80 %, which is reached already at early ages (before 10 years) and maintained during the rest of the life cycle of *C. ladanifer*, which also matches with the findings of the aforesaid research conducted by Salerni and Perini (2004) in a very different ecosystem.

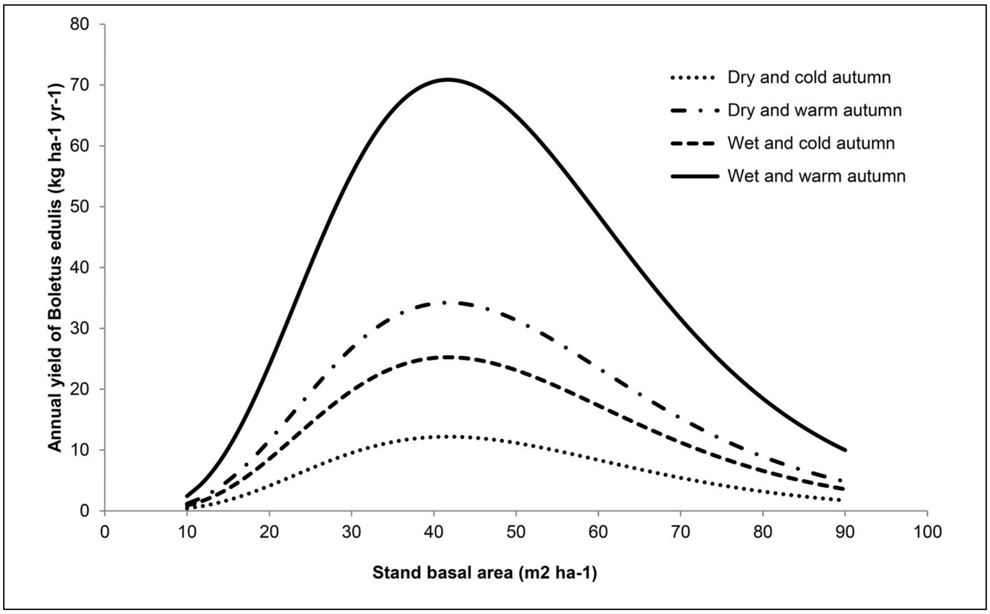

Figure 6.5. *Relationship between annual yield of B. edulis and stand basal area in Pinus sylvestris stands (Martínez-Peña et al. 2012).*

Under boreal conditions, Tahvanainen *et al.* (2016) found that *B. edulis* yields increased along with stand age until a certain point (30 years), after which the yields started to decline. They also reported that thinning can improve *B. edulis* yields, although only slightly. According to the simulation results, advanced thinning (i.e. five years earlier than recommended for timber production) was the most suitable schedule for *B. edulis* production. On the other hand, they also realized that *B. edulis,* as an ectomycorrhizal fungal species, suffers from regeneration cuttings of spruce stands. In such forest systems, *B. edulis* production increases along with stand development so that the highest yields are obtained just before the first commercial thinning (at the age of 25-30 years and stand basal area of 25 m2/ha). The yields of *B. edulis* increases after the first thinning and also after the second thinning but to a lesser extent. Thinning opens up the canopy and rainfall is more likely to wet the forest floor, which may promote mushroom yields after thinning.

CASE 6.4: *Silvicultural recommendations for Lactarius group deliciosus production*

Saffron milk caps (*L. deliciosus*) have been described as an early colonizer of plantations (early-stage fungi), and found in greatest abundance in young stands (Fernandez-Toirán *et al.* 2006). Martínez-Peña (2009) observed two peaks of production in Scots pine (*P. sylvestris*) forests of different age classes, the first peak occurring at the age of 16-30 years and the second one at the age of 70 years. However, Bonet *et al.* (2004) found saffron milk caps along all age classes and on all aspects of *Pinus sylvestris* plantations in North-east Spain. Such an apparent contradiction may be explained by the fact that open forest conditions with relatively low basal areas typical of the early stage of natural forest succession (before canopy closure), but that can be found also within mature stands, are favourable for saffron milk cap production. Thus, the use of silvicultural treatments to decrease the density of older stands may contribute to enhancing *L. deliciosus* production, assuming that forest stand structure is more relevant to saffron milk cap productions than stand age.
The empirical models for *L.* group *delicious* developed by Bonet *et al.* (2008) and Martínez-Peña *et al.* (2012) further supported the importance of stand basal area as the most relevant predictor, in terms of the silviculture and forest management for *Lactarius* yields. Bonet *et al.* (2012) found that light to moderate thinning treatments (i.e., around 10 m2/ha of basal area removal) affected positively *Lactarius* yields during the first two years after the forest thinning, whereas heavy thinning (i.e. beyond 35 m2/ha of removed basal area) would result in a reduction of fungal yields as compared with unthinned plots (Figure 6.6). Preliminary results based on the continuous inventory of mushrooms during the years 2011-2015 suggest that the thinning effect on the production of *L. deliciosus* group may fade away after two or three years after thinning. This suggests that *L. deliciosus* group has a high adaptive ability to different stand structures partly due to the particular and diverse habitat preferences of the individual species included in the group *deliciosus* (*Lactarius deliciosus*, *L. vinosus*

and *L. sanguifluus*). This also contributes to the idea that the *L. deliciosus* group prefers growing in relatively open forest conditions and when stand age is close to the period of highest tree growth. This coincidence sounds reasonable from the ecological point of view since saffron milk caps are ectomycorrhizal fungi that grow in symbiosis with forest trees. Based on that, one could expect that the maximum mushroom productivity matches with the maximum tree growth due to the high quantity of carbohydrates produced by the trees and shared with the mycorrhizal fungal communities. However, the analysis of such relationships conducted so far have shown no clear temporal synchronization between annual mushroom yields and seasonal wood formation, except for some pine stands growing on quite xeric sites (Primicia *et al.* 2016).

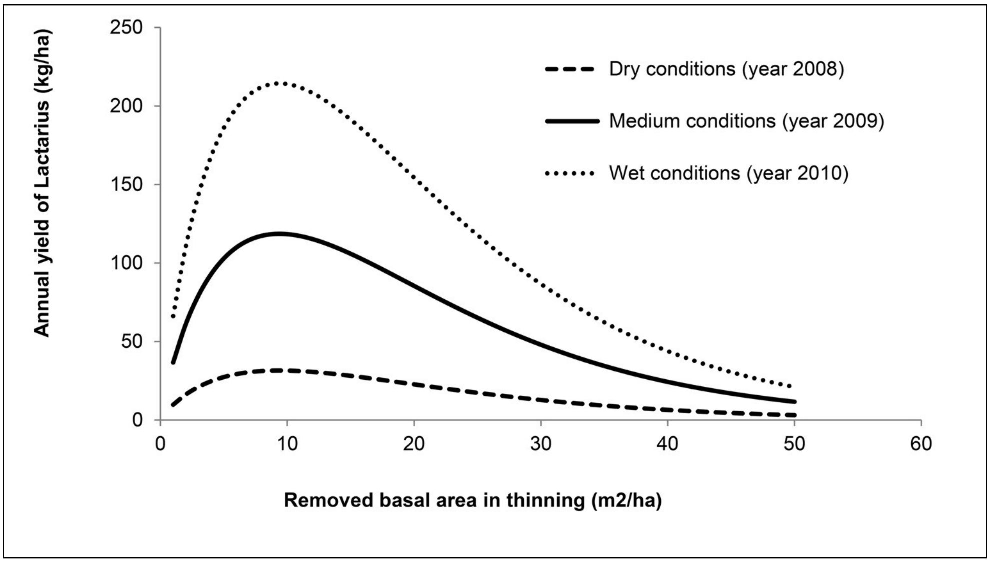

Figure 6.6: *Relationship between the annual yield of Lactarius group deliciosus and removed basal area in thinning in the years of study (Bonet et al. 2012).*

6.5 *Socioeconomy linked to mushrooms and truffles in rural areas*

Wild mushrooms have been used and traded as food or medicinal products practically everywhere in the world (Boa 2004). Each country has regulated the harvesting rights differently, with direct impacts on the socio-economic values created through the wild mushroom uses. Wild mushrooms may be commercialized as products for the international or niche markets, or as recreational service, in which a picker purchases a picking permit for collecting wild mushrooms. The economic performance may be very different according to the targets of policy makers. This subchapter reports a set of case studies through which we may understand the complexity and the potential value of European forests if proper policies are offered. Moving from the case of export-oriented countries like Serbia, we will describe the strategic effect of wild mushroom trade on the remote rural areas in Romania that are the key suppliers for Spain and Italy, countries where the commercialization of wild mushrooms is still an important activity for the local niche markets, while a new form of income is generated with the commercialization of picking permits or with the new establishment of truffle production in a country.

Trade is the main engine of the wild mushrooms economy that has had a positive growth in terms of volumes and values recently at a global scale (Pettenella *et al.* 2014). A general overview of European trade of wild mushrooms gives an understanding of the scale of the market and the implications that trade might have on the trans-boundary effects of national policy with regard to the market. The trade balance of EU28 (external and internal EU28trade) has been negative for the fresh and frozen mushrooms (Figure 6.7) according UN-Comtrade data, while only after 2012, the trade of dried and preserved mushrooms moved to a positive net balance, due to the increment of prices of Chinese supply (Figures 6.8 and 6.9).

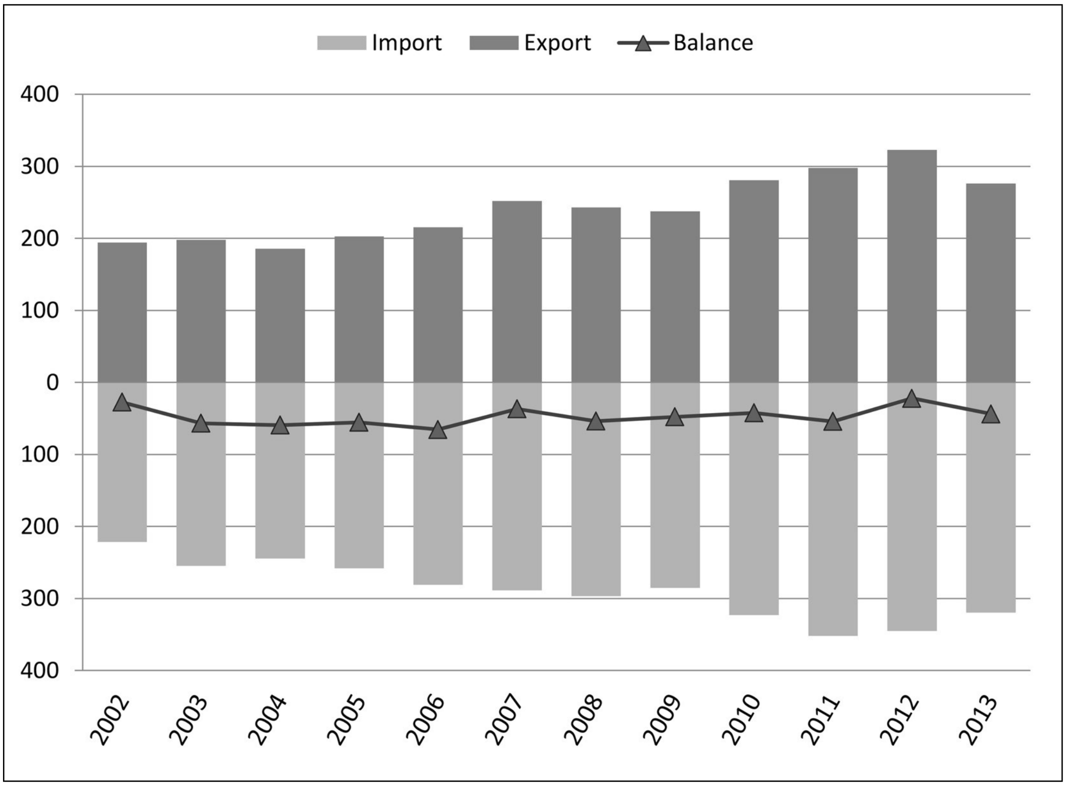

Figure 6.7: *EU28 trade balance for fresh and frozen mushrooms other than Agaricus species in million € (HS-070959)*

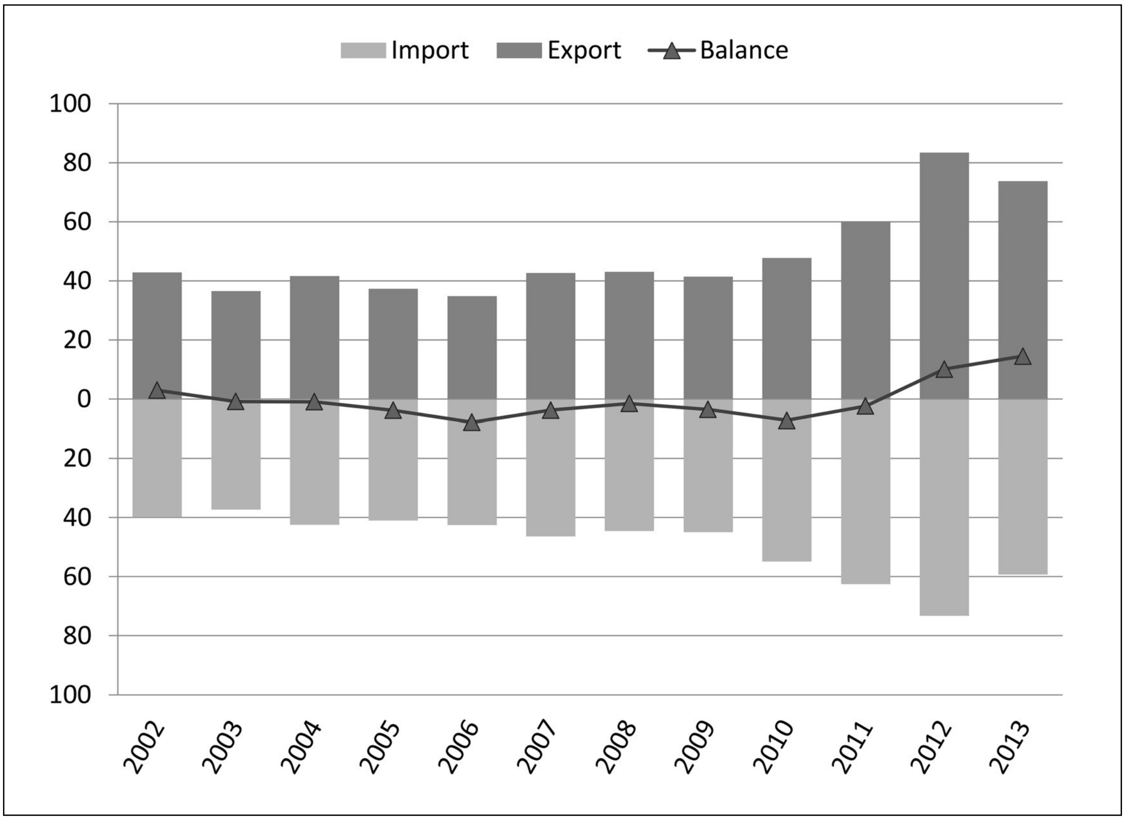

Figure 6.8: *EU28 trade balance for dried mushrooms other than Agaricus species in million € (HS-071239)*

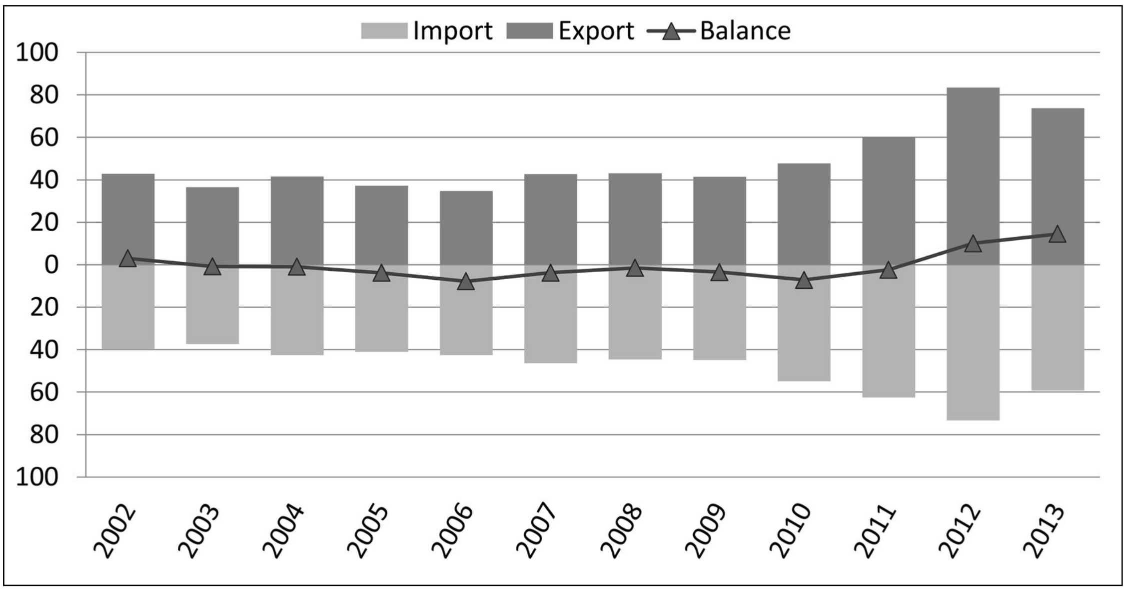

Figure 6.9: *EU28 trade balance for preserved mushrooms other than Agaricus species in million € (HS-200390)*

The estimations cannot be precise because a specific overview of wild mushroom trade would need higher resolution data, which may be only available in some countries through their official statistics. Anyhow, the UN-Comtrade database represents a key data source for studying the global overview of a commodity traded internationally. A precise trade overview can be done only for specific commodities like truffles, clearly with a positive net balance both as fresh and frozen product as well as final product (see Figures 6.10 and 6.11), thanks for the natural availability of truffles in Europe and the limited capacity of truffle plantation outside Europe.

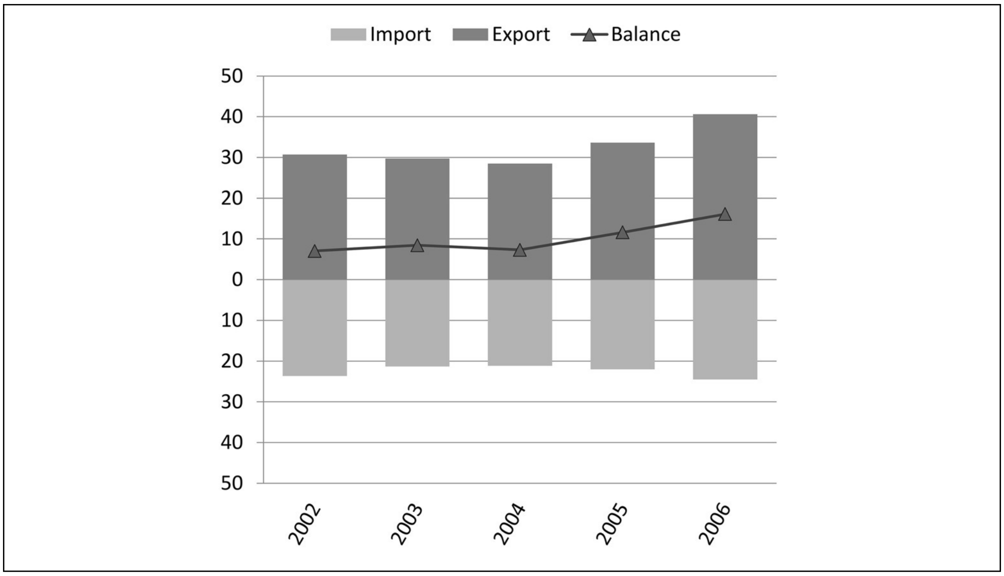

Figure 6.10: *EU28trade balance for fresh and frozen truffles in million € (HS-070952)*

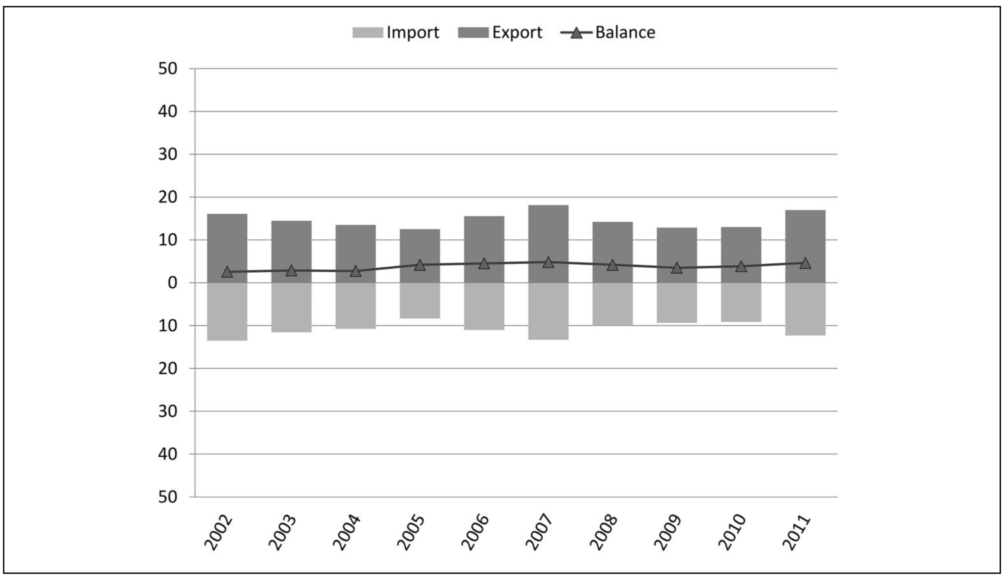

Figure 6.11: *EU28trade balance for preserved truffles in million € (HS-200320)*

International trade is affected by national policies that may stimulate or inhibit wild mushroom production and export. For instance, the Western Balkans, as well as Serbia, are known for a rich spectrum of wild mushrooms that facilitates a large scale use. Thanks to the increasing of European demand, Serbia has enabled companies to become more oriented towards export of wild mushrooms (Keča *et al.* 2014); in 2007, Serbia exported a little over 7 million € worth of fresh (chilled) forest mushrooms to the EU. In second place was the export of dried forest mushrooms, at about 6.2 million €, followed by preserved forest mushrooms at 2.6 million €. The collection and export of mushrooms is a highly regulated activity and the government establishes an annual quota for the collection of wild mushrooms, limiting the total quantity available for exports for the stimulation of products with added value (Keča *et al.* 2015). The production of wild mushrooms is very inconsistent due to the variability of the climatic conditions; consequently, the supplied quantity in the market follows the wild mushroom availability in the forest (Figure 6.12).

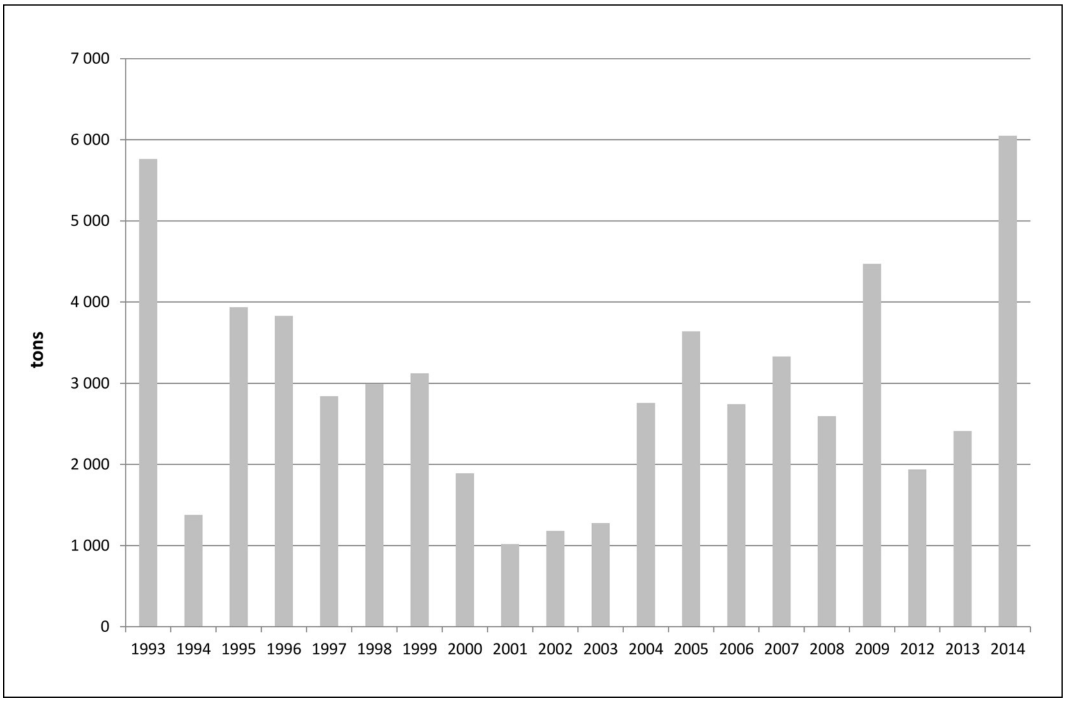

Figure 6.12: *Production of wild mushrooms in Serbia (in tons) (Source: Keča et al. 2015).*

Important species such as *Boletus edulis*, *Cantharellus cibarius*, *Craterellus cornucopioides*, *Lactarius deliciosus*, *Marasmius oreades*, *Tuber aestivum* and *T. magnatum* are collected by an estimated 125 000 individuals in rural areas (Keča *et al.* 2015). The forest productivity is around the 21.5 kg of wild mushrooms per hectare (Keča *et al.* 2013), a quantity that may be translated in terms of economic value that ranges approximately between the 40 and 60 €/ha considering the cep price. In general, wild mushrooms pickers sell their harvest to the "purchase stations", which are usually located near the wild mushroom companies. The pickers are a crucial element of the supply chain because they represent the suppliers for the 152 registered companies dealing with NWFP (Ministry of Agriculture and Environmental Protection, Internal document, 2015), among which 51 of them deal with mushrooms. A survey carried out on 43 wild mushroom companies showed that each company has on average more than 10 permanent workers, with an annual supply capacity of over 50 tonnes of mushrooms both for domestic and foreign markets (Keča *et al.* 2015). Moreover, the survey highlighted that the companies are generally involved in buying and processing of raw and semi-processed wild mushrooms, though they are moving quite fast on the commercialization of final products. Wild mushroom prices depend on the balance of supply and demand through the year (see Table 6.2). The price usually covers the main supply costs like the fee costs for the purchasing facilities, costs of raw materials, followed by the cost of cleaning, processing, packaging, transportation, as well as the costs of promotion and the time of year when mushrooms are harvested. Almost all enterprises indicated that the price at which they sold was decided on a “cost plus” basis, or in other words, a price set up multiplying the total cost by a factor that corresponds to the net profit the seller wants to have.

Table 6.2: Average prices of forest mushrooms in Serbia (Source: Keča *et al.* 2015)

Product	Average price (€/kg)
Dry Chanterelles	12.25-53.9
Dry Boletes	9.3-49.1
Fresh Chanterelles	3.43-16.38
Brined Chanterelles	2.25-12.26
Brined Bolete	2.25-11.77
Deep frozen mushrooms	5.40
Fresh Bolete	2.21-2.94

Another case of an export-oriented country is Romania, in which the wild mushroom trade allows the transfer of a consistent flow of money to remote rural areas. Well recognized for the richness of its forests, Suceava is an administrative unit located in North-East Romania with good natural conditions for mushroom production. Mushroom collection is traditionally practiced by household members for personal consumption and by poor segments of the rural population to supply local markets. For almost ten years, there has been an intensive trading of mushrooms and berries along the main road crossing the region. Alongside this, an export-oriented mushroom business is flourishing, with collection points all around the Suceava county. This facilitates the transfer of the harvest to a large processing centre in Western Romania. The official production sold every year by the national forest administration in Suceava region accounts on average for 150 tonnes, though specific studies seem to indicate a production of 50 tonnes sold on the informal market (Bouriaud *et al.* 2015a). The mushroom business in the region is based on an estimated number of 600 to 700 pickers. Less than 100 of them are selling the mushrooms directly at the roadside or in the farmers' markets, and some 500 to 600 sell the collected mushrooms to the trading firms or intermediaries. In Suceava, there are in total ten firms legally registered, which rely also on an undefined number of intermediaries acting on behalf of other firms located in Suceava or other surrounding regions. For instance, the study conducted by Bouriaud *et al.* (2015a) indicates at least seven firms in this semi-legal situation, but the real number may be substantially higher.

Pickers can generate an important income from wild mushroom collection. This is done on a family or a group network basis with an average number of four persons in case of families or eight in case of larger networks organized during the season (May to September). For most of the pickers, the income from mushroom selling represents the only or a substantial part of the family income (Bouriaud *et al.* 2015b). In a good season, they can sell between 10 to 60 kg of mushrooms per day (usually cep and chanterelle, but also *Armillaria* spp. at the end of the season). The quantities unsold at the end of the day will be consumed by the household. At a price of 2,5 €/kg (cep, end of 2014 season), and a number of 30 working days, the monthly income varies between 750 € and 4,500 € in the case when mushrooms are sold directly in the farmers' market or next to the road. The income is shared amongst the collectors, that means on average four people (family) or eight (larger pickers' networks), which means that the income may reach up to 2,500 € for a family with one or two children. This data is confirmed in another study published in a German newspaper (Cadenbach 2015), which quotes a 22 € income per day per person from mushroom picking by Roma people in Western Romania. All these results do not consider the pickers' costs for transportation that varies between 10 and 100 km to reach the collecting places by train or car. When the production is sold to intermediaries, the estimated income is less than half of this figure (one family may get between 500 to 1,000 € income per season) meaning that pickers earn more when selling the harvest directly to the final customer along the road than when selling to the firms. This is due to the fact they do not pay any tax and they do not pay any fee for the right to collect the mushrooms in the forests, a right which is normally reserved to the forest owner, but rarely enforced. The income generated by wild mushroom picking is used for immediate consumption like food, firewood, sometimes something for the home (e.g. a TV) or for paying school-related items (the school is free of tax, but some social categories cannot afford to pay appropriate shoes and clothes for sending children to school). Almost all the pickers are entitled and receive social assistance from local government, as they belong to a very poor social category. For this reason, some of the people interviewed were reluctant to speak about their mushroom-related income. On the other hand, in the rural areas where the pickers live, there are scarce employment opportunities. For instance, a municipality of 5,000 inhabitants may have only 240 employed people. In general, the active population in rural areas is occupied with subsistence agriculture. However, most of the pickers do not own land. They sell therefore their traditional knowledge on mushroom picking, getting an income critically needed for family welfare.

The two examples of Serbia and Romania show how important the economy of wild mushroom business is for rural development; especially the case of Romania demonstrates the crucial importance on household welfare where the state often fails to support economically poor segments of the rural society. Despite the fact that many authors bind NWFP with poverty (Marshall *et al.* 2006), the wild mushroom economy may be an important source of income for the forest managers in the industrialized countries even if the wild mushrooms are sold more as a service rather than a product. One example of how edible mushrooms can impact in a rural development is the case of Castilla y León region in Spain. The region has more than 4.5 million productive hectares, of which 1.5 million hectares are forests with great capacity for the production of edible wild mushrooms with a high market value. These include species recognized around the world as the black truffle (*Tuber melanosporum*), cep (*Boletus edulis* group), saffron milk caps (*Lactarius deliciosus* group), chanterelles (*Cantharellus cibarius*), St. George's mushrooms (*Calocybe gambosa*), morels (*Morchella* spp.), and more than 50 other wild edible species. Castilla y León also has centuries-old forests and a high level of use and management of mycological resources that, although still very much emerging, is one of the most developed in Spain (Martínez-Peña *et al.* 2012). It is estimated that every year the rural areas communities of Castilla y León receive an average of 251,029 mushroom tourists from the urban areas of different Spanish regions including Castilla y León. These harvesters (tourists and day-trippers) spend money in the rural areas during their harvesting visits. The region also attracts other tourists and day-trippers every year for mycological culture or food, who are not necessarily harvesters (Latorre 2014). It is estimated that the mycological sector of Castilla y León can, in a good year, generate up to 65 million €, of which 20% is direct income from harvesters selling mushrooms, 40% is value added by the agro-food industry, 39% is value added by mycotourism and 1% is ownership rights (Martínez Peña *et al.* 2015). The same source also calculated that approximately 50% of restaurants in the region serve wild mushrooms, thus generating added value greater than 9 million € /year. Average yearly costs for a mycotourist was estimated of 130.6 €. Nevertheless the estimation may be higher or lower if we consider that a mycotourists in Castilla y León who stayed overnight spent 214.7 € per person per year or day-trippers that spend approximately 72.8 € per person per year. Applying this value to the total number of mycotourists estimated above, the total average spending of mycotourists in Castilla y León is estimated at 32.7 million € (Latorre 2014). After more than ten years of consolidation of the program of mycology of Castilla y León and around 8.5 million € invested by the regional government and provincial councils (52%), the European Union (38%) and the Spanish State (10%), Castilla y León is a region recognised internationally[28] . The system currently runs without a public subsidy thanks to the average annual income of 0.5 € per hectare generated by the sale of harvesting permits, which guarantees the control of mushroom use and respects their ownership rights, while also allowing locals and visitors to collect mushrooms. In June 2016, the program had 408,893 hectares of public forests in Castilla y León where mushroom harvesting was regulated through the issue of permits.

CASE 6.5: *Truffle cultivation in Austria – domestication of an ectomycorrhizal gourmet fungus?*

In Austria, local truffling was almost forgotten, and truffle cultivation had not yet been established. The legal status of harvesting wild truffles in Austria is complex (nine different federal laws regulating nature protection and fungi collection. A project (1998-2002; Austrian Research Promotion Agency co-funded), laid the foundation for documenting truffling in Austria (e.g. Urban and Mader 2003), for the discovery of previously not reported truffle species (e.g. *T. brumale*; Urban and Pla, unpubl.), and for research on truffle cultivation. The project resulted in the foundation of TrüffelGarten (supported by INITS, an incubator for academic spin-offs), a company producing controlled mycorrhized seedlings and providing consultation for truffle plantation establish- and management. The initiators of truffle cultivation in Austria did not promote harvesting of wild truffles or, specifically, the training of truffle hunting dogs, to avoid conflicts with stakeholders and nature conservation. Wild truffle populations are primarily considered as a valuable genetic resource for truffle cultivation (Urban and Pla 2009).

The main Tuber species currently cultivated in Austria as a NWFP is *T. aestivum* f. *uncinatum*, the Burgundy truffle. The different eco- and genotypes of *Tuber aestivum* s.l. (Molinier *et al.* 2016) cover a wide amplitude of ecological conditions and habitat characteristics. Its cultivation has a large potential in Austria (Chevalier 2012), but truffle orchard management is less studied, compared to the Périgord truffle (*Tuber melanosporum*). The Tuber *aestivum/uncinatum* European Scientific Group (TAUESG) promotes research and exchange on this species on a European scale. In Austria, most habitats currently known are in planar, colline and submontane zones, typically on lime-rich soils, suggesting that this species is limited by colder climates and the more acidic soils prevailing at higher elevations.

28 See for instance the three main Projects related to mycotourism developed by Castilla y Leon: www.micocyl.es, www.micosylva.com, www.mercasetas.es

Since the foundation of TrüffelGarten in 2003, many plantations have been established in Austria and in other European countries, by private initiative and investment. This resulted in a multitude of experiments with little scientific monitoring, due to a lack of funding. Since the first harvest of a cultivated Burgundy truffle in October 2008, the results are increasingly promising, however, due to a lack of irrigation facilities in most plantations, highly dependent on climatic conditions. In 2016, after abundant precipitation in spring and summer, the season provided a major harvest by July (Figure 6.13) in a plantation first established in 2004. In several other plantations, first harvests were recorded (http://www.trueffelgarten.at/aktuell/).

Truffle cultivation in Central Europe opens up many possibilities for gastronomy, tourism, rural economy and sustainable development. More funded research is needed to optimize plantations making yields more reliable and amplifying the success of truffle cultivation as a NWFP.

Figure 6.13: *Truffle production in Austria (Photo credits: A. Urban)*

The brief description of the above-mentioned case studies show the real possibility to develop a wider income portfolio from the forest sector. Achieving this with wild mushrooms is not easy but potentially wild mushrooms can readily contribute to household incomes and welfare in remote rural areas. Commonly policy makers pay little attention to the economy that can be generated from wild mushrooms and other NWFP, but there is a clear need for companies and citizens to promote a slow change toward a greener economy. In a recent study (Vidale *et al.* 2016), it was highlighted that the future policies on wild mushroom collection should go far beyond the harvest limitations in terms of quantity. They also should consider these new professional activities of the forest sector within a fiscal system that takes into account the high-risk annual weather conditions on yields, as in the described Serbian case.

6.6 Conclusions

Forest fungi play a key role in forest ecosystem functioning by contributing to nutrient turnover from litter and wood, tree nutrition and carbon sequestration. Fungi are also an important piece of the biodiversity puzzle. Approximately 12,500 fungal species of macrofungi alone grow in Europe, which means that fungal species richness is higher than in the case of animals or plants. In addition, wild edible fungi are also considered a valuable NWFP throughout the world. Fungal fruit bodies have been traditionally used by different civilizations up to the point that more than 1,100 fungal species are consumed worldwide as food or medicine (the number rises to 2,800 species if uses such as cosmetics or toxicology are also considered). However, the knowledge on mushrooms and the species used vary among different regions of the world. For instance, 268 fungal species are authorized for trade in all the European countries with relevant differences between countries. In spite of the growing interest in mushrooms and truffles in Europe, little is known about fungal productivity as well as about the different factors influencing the presence of the fungal fruit bodies in different forest ecosystems. This is mainly due to the short aboveground appearance of those species which implies conducting long-term monitoring and repetitive inventories in order to properly characterize fungal communities in target ecosystems. The consequence is the scarce scientific information on fungal ecology and productivity throughout Europe. This also implies that forest managers who wish to optimize forest conditions for enhancing mushroom production do not have sufficient site-specific or species-specific information available for developing a suitable fungal-oriented forest management by means of the so-called mycosilviculture. This chapter aimed to compile the scattered available information on fungal ecology, productivity and socioeconomics, summarizing the suitable techniques and tools for enhancing mushroom and truffle production within the context of the multifunctionality of European forest ecosystems.

In spite of the growing interest on the forest mushrooms and the consequent increase of research efforts, gaps of knowledge still exist. As a conclusion of the chapter, the authors identified the need of further research in the next key points:

- There is an unbalanced knowledge about fungi in Europe. Therefore, there is a need for increasing research efforts towards developing the missing national red checklists of endangered fungi species.
- The factors affecting mushroom emergence need to be further understood. Besides the effects of site, stand and weather variables on mushroom yields, the interactions of these variables also need to be clarified.

- Scenarios for landscape change associated with global change are needed and how this may affect the fungal communities.
- Long-term effects of forest management practices need to be monitored and analyzed. Forest management practices which favour mushroom yields need to be identified.
- Besides *Tuber* species, (semi)cultivation of other ectomycorrhizal species need to be studied.
- More research on fungal communities is needed with broadleaved tree species, rather than coniferous species.
- There is a need to carry out long-term studies on the dynamics of fungal communities.
- There is a need to estimate the economic impact of the global climate change on mushroom fruiting and thus trading possibilities at different scales (from local to global).
- There is a need to highlight the real value of the mushroom market (informal market) and its contribution to the rural economies and especially to low income groups.
- Harmonization of policies at European scale (for example: toxicology. – i.e.: *Tricholoma equestre*) are necessary.

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11 Appendix

11.1 Glossary

Aromatic plants Plants that produce and exude aromatic substances mainly volatile compounds known as essential oils that broadly used in food industry, cosmetics, animal breeding, agriculture.

Ascomycete Fungi that, together with the Basidiomycete, from the subkingdom Dikarya of the kingdom Fungi. Ascomycete are the largest phylum of Fungi with over 64,000 species, including species of commercial interest such as morels or truffles.

Basal area Is the area of a given section of land that is occupied by the cross-section of tree trunks and stems at the base.

Basidiomycete Fungi that, together with the Ascomycete, from the subkingdom Dikarya of the kingdom Fungi. Basidiomycete includes valued species such as chantarelles or boletes.

Bioavailible The availability of chemical or compound for absorption by plant or animal tissue in a defined form or state.

Brand unique design, sign, symbol, words, or a combination of these, employed in creating an image that identifies a product and differentiates it from its competitors. Over time, this image becomes associated with a level of credibility, quality, and satisfaction in the consumer‘s mind (Source: http://www.businessdictionary.com).

Decision support system (DSS) A tool that provides support to solve decision problems by integrating user interface, simulator, expert rules, stakeholder preferences, database management and optimization algorithms.

Certification (from ISO) the provision by an independent body of written assurance (a certificate) that the product, service or system in question meets specific requirements (standard).

Ectomycorrhiza Form of symbiotic relationship that occurs between a fungal symbiont and the roots of various plant species that acts as a host

Ectomycorrhizal The symbiotic relationship between a fungus and the tissues of various plant species.

Empirical model A model that is developed using statistical techniques and calibrated with an empirical data set measured in the field.

Epigeous fungi The fruit body of the fungi grows on or close to the ground.

Expert-based model A model that is developed using a data set of quantitative expert judgements when empirical data are not available or cannot be measured.

Explanatory variable In a modelling framework, each of the factors – continuous or categorical – that influences and causes changes over the response variable, which is the focus of the research. When the model is expressed as a mathematical equation, the explanatory variables are those whose value is given as an input of the model. Also known as independent variable or predictor.

Forest inventory Collection, summarization and processing of the information related with the stock, availability, potential use and spatial distribution of a given biological resource located in the forest

Forest model A dynamic representation of the forest and its behaviour, at whatever level of complexity, based on a set of (sub-)models or modules that together determine the behaviour of the forest as defined by the values of a set of state variables as well as the forest responses to changes in the driving variables

Forest Ownership Refers to the legal right to freely and exclusively use, control, transfer, or otherwise benefit from a forest (trees growing on land classified as forest). Ownership can be acquired through transfers such as sales, donations, and inheritance.

Forest Statistics A compilation of statistics at national or regional level providing information on production, harvesting and trade statistics for forest products. Apart, general information on such topics as woodland area, annual planting activity, forest ownership, employment, finance & prices… is also provided

Future-proof food (NWFP and wild forest products) following the definition given by the EC in the European Research & Innovation for Food & Nutrition Security report (EC, 2016) future-proof food are more sustainable, resilient, responsible, diverse, competitive, and inclusive food products:

- Sustainable: with respect to natural resource scarcity and in respect of planetary boundaries;
- Resilient: with respect to adapting to climate and global change, including extreme events and migration;
- Responsible: with respect to being ethical, transparent and accountable;
- Diverse: with respect to being open to a wide range of technologies, practices, approaches, cultures and business models;
- Competitive: with respect to providing jobs and growth;
- Inclusive: with respect to engaging all food system actors, including civil society, fighting food poverty, and providing healthy food for all.

Grazing intensity The proportion of the current season's forage production that is consumed or trampled

Growing Stock Volume over bark of all living trees with a certain minimum diameter at breast height. Includes the stem from ground level up to a top, excluding branches (but considering a limit diameter; branches > 7cm count), twigs, foliage, flowers, seeds, and roots.

Growth and yield model A set of models that predicts the structure and development (regeneration, increment and mortality) of a forest stand.

Hypogeous fungi The fruit body of the fungi grows below-ground.

Ideotype The description of the idealised appearance of a plant variety (see Donald 1968).

Informal economy system of trade or economic exchange used outside state controlled or money based transactions. Practiced by most of the world's population, it includes barter of goods and services, mutual self-help, odd jobs, street trading, and other such direct sale activities. Income generated by the informal economy is usually not recorded for taxation purposes and is often unavailable for inclusion in gross domestic product computations. (Source: http://www.businessdictionary.com).

Livestock grazing The grazing of domestic animals that are raised on a farm. In some cases, the term is referred only to the ruminants (cattle, sheep and goats).

Management Plan Supports the planning of management activities on a forest area that has a long-term management goals, which is periodically revised. The plan may refer to forest management unit level or smaller units (stands or compartments) and describes activities planned for individual operational units but may also provide general strategies planned to reach management goals.

Medicinal plants Plants that are used by humans for therapeutic, tonic, purgative, or any other health-promoting purposes. It could be used any part of the plants (leaves, roots, seeds, bark).

Model A mathematical description of the real world in a simplified way.

Multi-purpose management Forest area designated primarily for more than one purpose and where none of these alone is considered as the predominant designated purpose. Forest management might focus on provisioning services in the form of wood, but also at the co-production of other products (like non-wood forest products), livestock grazing, recreational or watershed services including the conservation of ecosystems and biodiversity.

Mycelium Vegetative part of a fungus consisting of a mass of branching, thread-like hyphae. Fungal colonies composed of mycelium are found in and on soil and many other substrates

Mycosilviculture Array of silvicultural treatments and operations aiming at enhancing the provision of mushrooms and truffles in order to integrate these products into multifunctional forest management planning.

National Forest Inventory The systematic collection of data and forest information such as, situation, property and protection regime, nature, legal status, probable evolution, production capacity, etc., of all types of forest goods at a countrywide level for making high-level policy decisions and broad-scale resource monitoring.

Non-timber forest products (NTFP) NTFP is often used as a similar term for non-wood forest products (NWFP). The main difference between NTFPs and NWFP is, that NWFP exclude all wood products and NTFPs do not exclude wood products such as fuel-wood, artisanal use of wood or charcoal.

Non-wood forest products (NWFP) All tangible goods of biological origin (with the exception of wood products) that are derived from forests and wooded land, and also from trees outside the forest (see FAO 1999 and Belcher 2003).

“Direct NWFP” are often considered as products that are directly derived from a particular tree species i.e. cherries or walnuts from *Prunus avium* or *Juglans regia* respectively. “Indirect NWFP” are often considered as species that co-exist with trees when provided with certain site conditions that the overstory bestow for example mushrooms and truffles, e.g. *Boletus edulis*.

Nutraceutical A standardised nutrient of pharmaceutical-grade.

Permanent plot Plot installed with the main aim of continuous research on the evolution, dynamics and continuous resource assessment of the forests. They are commonly established and measured at the start of an investigation and subsequently remeasured at fixed intervals over a period of a few to many years. For the period of observation, permanent plots provide points in a real growth and yield series, as opposed to artificial growth and yield series constructed from single measurements of stands subjectively selected to represent successive stages in development.

Plantation Forest predominantly composed of trees established through planting and/or deliberate seeding. Includes rubberwood, cork oak and Christmas tree plantations.

Process-based model A model that describes and simulates the behavior of a system derived from a set of functional components and their interactions with each other and the system environment, through physical and mechanistic processes occurring over time.

Production Forest Forest area designated primarily for the production of wood, fibre, bio-energy and/or non-wood forest products.

Raw materials The basic plant material from which a product is made.

Resource assessment The interpretation and evaluation of data obtained from inventory against some objective or standard, aiming to attain the optimal utilization of the resource under the constraints given in the framework of the forest management planning.

Sampling inventory A sample-based survey of the forest resource. The main aim is to quantify the abundance of a given biological resource (timber, biomass, NWFP...) in the forest using sound statistically based procedures and optimal sampling techniques.

Saproxylic Organisms that feed on dead wood.

Silviculture The combination of different forest measures (e.g. planting, tending, thinning) to ensure continuous and sustained production of a defined production goal including benefits that can be directly or indirectly derived from trees, plants, water and wildlife within forested areas.

Simulator A tool that uses mathematical models for calculation and presentation of outcomes of a set of stand management scenarios.

Stand basal area The sum of the cross-sectional areas at breast height (1.30 meters aboveground) of trees growing within a forest stand, using square meters per hectare as the typical measurement unit.

Stocking rate The relationship between the number of animals and the total area of the land that is utilized over a specified time.

Traceability in supply chain traceability is the ability to identify, track and trace elements of a product as it moves along the supply chain from raw goods to finished products.

Transect Sampling technique based on making observations of the subject resource walking along a prepared trail of known length. It is widely used for monitoring wild animals, or plant species which form dense contiguous cover, e.g. ground flora

Understory plants All the plant species below the canopy. In some cases, the term "understory" used only for species of shrub size or smaller.

Value chain the set of activities for producing and marketing a product or service involving the acquisition and consumption of resources – money, labour, materials, equipment, buildings, land, administration and management.

Wild products Plant resources that are grown in natural ecosystems and are collected by humans for food, dietary supplements or medicinal proposes.

11.3 List of species by NWFP category type

Mushrooms and Truffles	Tree Products	Understory Plants	Animal Origin
Agaricus spp.	*Abies alba*	*Allium ursinum*	*Alces alces*
Albatrellus pes-caprae	*Abies fraseri*	*Arbutus unedo*	*Alectoris barbara*
Amanita caesarea	*Abies koreana*	*Arctostaphylos uva-ursi*	*Alectoris chukar*
Armillaria mellea	*Abies lasiocarpa*	*Arnica montana*	*Alectoris graeca*
Boletus (Xerocomus) badius	*Abies nobilis*	*Asparagus acutifolius*	*Alectoris rufa*
Boletus aereus	*Abies nordmanniana*	*Cistus ladanifer*	*Anas platyrhynchos*
Boletus aureus	*Aesculus hippocastanum*	*Clematis vitalba*	*Apis mellifera (inc. subsp mellifere)*
Boletus edulis	*Argania Spinosa*	*Convallaria maialis*	*Capra aegagrus*
Boletus mamorensis	*Betula pendula*	*Dactylis glomerata*	*Capra ibex*
Boletus reticulatus	*Betula pubescens*	*Sphagnum spp.*	*Capreolus capreolus*
Cantharellus cibarius	*Carpinus betulus*	*Polytrichum spp.*	*Castor fiber*
Cantharellus lutescens	*Castanea sativa*	*Pleurozium schreberi*	*Cervus elaphus*
Chlorophyllum rhacodes	*Ceratonia siliqua*	*Pseudoscleropodium purum*	*Columba palumbus*
Chlorophyllum olivieri	*Cornus mas*	*Empetrum nigrum*	*Cornu aspersa*
Chlorophyllum brunneum	*Corylus avellana*	*Filipendula ulmaria*	*Coturnix coturnix*
Craterellus cornucopioides	*Fagus sylvatica*	*Fragaria vesca*	*Dama dama*
Craterellus lutescens	*Frangula alnus*	*Frangula alnus*	*De-domesticated cattle*
Ganoderma lucidum	*Ilex aquifolium*	*Galium odoratum*	*Lepus capensis*
Gyromitra esculenta	*Inonotus obliquus*	*Gentiana lutea*	*Lepus europaeus*
Lactarius deliciosus (group deliciosus)	*Juglans regia*	*Geranium sylvaticum*	*Lyrurus tetrix*
Lactarius deterrimus	*Juniperus communis*	*Hippophae rhamnoides*	*Marten marten*
Lactarius rufus	*Larix decidua*	*Hyacinthoides non-scripta*	*Odocoileus virginianus*
Lactarius trivialis	*Malus sylvestris*	*Hypericum perforatum*	*Oryctolagus cuniculus*
Leccinum albostipitatum	*Picea abies*	*Juniperus communis*	*Ovis musimon*
Leccinum aurantiacum	*Picea glauca*	*Lycopodium clavatum*	*Pacifastacus leniusculus*
Leccinum scabrum	*Picea omorica*	*Myrtus communis*	*Phasianus colchicus*
Lentinula edodes	*Picea parryana*	*Origanum compactum*	*Rangifer tarandus*
Marasmius oreades	*Picea pungens*	*Origanum vulgare*	*Rupicapra rupicapra*
Mattirolomyces terfezi-doides	*Pinus cembra*	*Ribes spicatum*	*Salmo trutta (inc. subsp. Fario)*
Morchella conica	*Pinus contorta*	*Rosa canina*	*Sus scrofa*
Morchella elata	*Pinus halepensis*	*Rosmarinus officinalis*	*(inc. subsp. Barbarous)*
Morchella esculenta	*Pinus nigra*	*Rubus chamaemorus*	*Tetrao urogallus*
Morchella vulgaris	*Pinus pinaster*	*Rubus fruticosus*	
Pleurotus ostreatus	*Pinus pinea*	*Rubus hirtus*	
Russula cyanoxantha	*Pinus strobus*	*Rubus idaeus*	
Suillus grevillei	*Pinus sylvestris*	*Sideritis spp.*	
Suillus luteus	*Pistachia lentiscus (inc. var. Chia)*	*Thymus satureioides*	
Terfezia arenaria	*Populus spp.*	*Thymus vulgaris*	

Tirmania spp.	*Prunus amygdalus*	*Thymus zygis*	
Tricholoma caligatum	*Prunus avium*	*Thymus mastichina*	
Tricholoma equestre	*Pseudotsuga menziesii*	*Urtica dioica*	
Tuber aestivum	*Quercus robur*	*Vaccinium myrtillus*	
Tuber magnatum	*Quercus petraea*	*Vaccinium oxycoccos*	
Tuber melanosporum	*Quercus suber*	*Vaccinium vitis-idaea*	
	Quercus ilex	*Valeriana celtica*	
	Robinia pseudoacacia		
	Salix viminalis		
	Sambucus nigra		
	Sorbus aucuparia		
	Sorbus torminalis		
	Tilia cordata		
	Tilia platyphyllos		
	Tilia rubra		
	Tilia tomentosa		
	Tilia argentea		