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Is silviculture able to enhance wild forest mushroom resources? Current knowledge and future perspectives

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ABSTRACT

Fungal fruit-bodies are an important economic resource both for recreational pickers and commercial markets. The broad interest in forest fungi and mushrooms has motivated attempts to develop appropriate silvicultural methods able to preserve and improve mushroom yields. Defining best practices for the sustainability and profitability of forest fungal resources is the main aim of 'mycosilviculture'. However, the difficulty of monitoring and studying such a cryptic kingdom (i.e., fungi) under real forest conditions has led to rather scattered scientific knowledge of the effects of forest management regimes and silvicultural operations on wild mushroom resources. Here, we review the current scientific literature regarding the influence of (i) stand characteristics, i.e. stand age, stand density, canopy cover and tree species composition, (ii) silvicultural practices and (iii) other management-related disturbances affecting the yield of wild epigeous mushrooms, with the aim of systematizing existing scientific knowledge and identifying gaps in knowledge in order to suggest future lines of research. Most of the research in the field of mycosilviculture to date has focused on ectomycorrhizal mushrooms, which include the majority of wild commercial mushrooms. The main findings from the literature indicate that forest management practices, by modifying stand characteristics and microclimatic conditions, can influence wild mushroom occurrence and productivity, both positively and negatively, depending on the specific fungal ecological needs, reproductive strategies, forest type and management regime. Further research efforts relating to all aspects of the interaction between forest management, fungal ecology and mushroom production are needed: in particular, additional research efforts should be devoted to understanding mushroom yield dynamics in uneven-aged and mixed forests and evaluating the effects of regeneration methods on fungal communities.

1. Introduction

Fungi are widely recognized as fundamental components of biodiversity and ecosystem functioning. Furthermore, fungal fruit-bodies, which constitute the main resource of an important socioeconomic activity based on mushroom picking for both recreational purposes and commercial markets, provide important provisioning and cultural ecosystem services to society. The commercial value of mushrooms can exceed 40 million euros (€) in countries such as Italy (ISTAT, 2008) or 32 million € in regions such as Catalonia (Bonet et al., 2014). The value derived from mushrooms is even higher if we also consider the recreational value of mushroom picking as a leisure activity (Martínez de Aragón et al., 2011; Latorre, 2016). Indeed, the economic profit from wild mushrooms can be higher than timber revenues (Palahí et al., 2009; Pettenella and Secco, 2006), especially in areas where timber production is not very profitable. Furthermore, the economic profit from wild mushrooms can represent a considerable percentage (up to 25%) of the soil expectation value, even in countries such as Finland where timber production is an important economic activity (Tahvanainen et al., 2016). De Román and Boa (2006) calculated that a family of four people living in a rural area of Northern Spain can derive profits of 5600–8400 € from picking saffron milk caps (*Lactarius deliciosus s.l.*) over the course of a season. In Eastern Finland, Cai et al. (2011) reported that the seasonal earnings of professional pickers were 1224 euro (more than 5% of the average net annual household income in Finland) and more recently Sisak et al. (2016) reported that three quarters of the rural households in the Czech Republic collect Non Wood Forest Products (NWFPs) (mainly mushrooms and berries). However, quantifying the exact contribution of mushrooms to household incomes in economic terms may still be underestimated due to the difficulty in accurately estimating the amount of wild mushrooms that are sold (because the economy is largely informal) (Maso, 2008).

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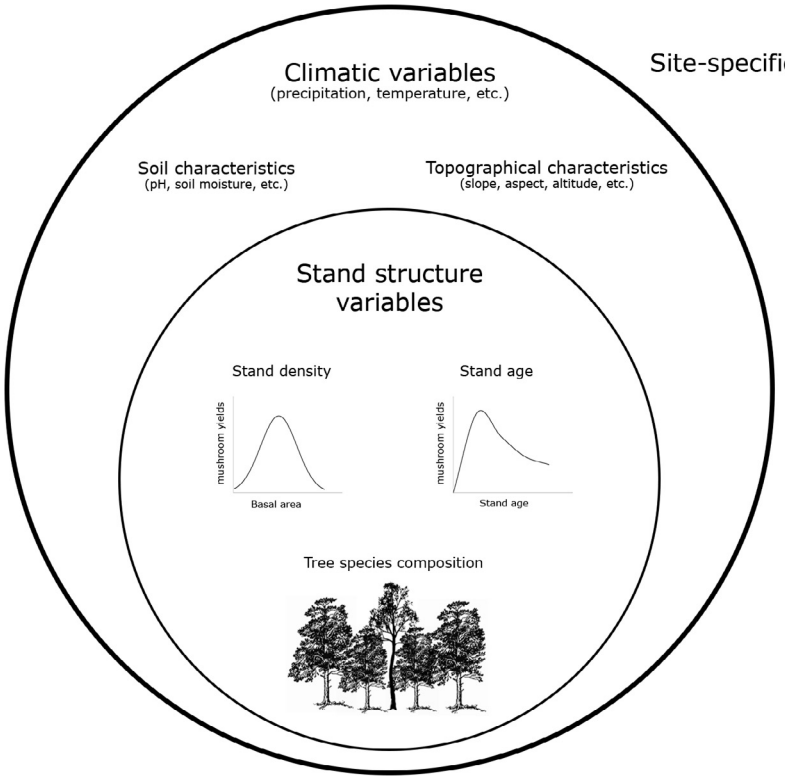

Fig. 1. Site-specific variables influencing mushroom yield. The inner circle denotes drivers typically modified through silviculture and forest management.

The twofold importance of wild forest mushrooms in ecological and socioeconomic terms underlines the need for promoting and preserving this resource (Dettori et al., 2009). For these reasons, forest management regimes oriented toward the provision of wild mushrooms need to be based on reliable quantifications of the impact of anthropogenic disturbances on mushroom yields, which also implies an in depth scientific knowledge of the key drivers that affect fungal communities.

Sporocarp production has been the focus of many studies (Vogt et al., 1992) and numerous variables influencing mushroom production have been identified. In addition to specific plant–fungal interactions, other key factors affecting sporocarp emergence include climatic conditions and soil and topographical characteristics (Fig. 1). Water availability is fundamental for fruit-body formation (Wiklund et al., 1995; Ogaya and Peñuelas, 2005; Büntgen et al., 2012). In particular, mean monthly precipitation and accumulated mean monthly evapotranspiration are strongly related to annual fruit-body production (Martínez de Aragón et al., 2007; Taye et al., 2016). Climatic conditions may also affect mushroom production in the long term (Gange et al., 2007; Kauserud et al., 2008; Ágreda et al., 2016) as a consequence of climate change. However, climatic or site conditions alone do not completely explain mushroom occurrence (Barroetaveña et al., 2008; Egli et al., 2011; Krebs et al., 2008) because the interactions between individual meteorological variables and other ecosystem variables are quite complex (Egli et al., 2011).

Stand structure characteristics (e.g., tree species composition, stand age, and stand density) influence mushroom yields (Fig. 1). Identifying stand characteristics that enhance the productivity of edible and marketable wild mushrooms is also the basis for the development of decision-support tools based on predictive models, which are being used to select optimal forest management alternatives for the provision of multiple ecosystem services, e.g., the joint production of mushrooms and timber (Palahí et al., 2009; Tahvanainen et al., 2016).

The growing interest in mushroom production has led to the development of a promising new discipline over the past few decades: “mycosilviculture”. According to Martínez-Peña et al. (2011), mycosilviculture attempts to integrate timber and mushroom production into the management of forest ecosystems. However, a broader, more generalized definition of mycosilviculture based on existing formal definitions of silviculture (e.g., Ciancio, 1981; Ciancio and Nocentini, 1997) is: the experimental science studying the interactions between the natural dynamics of forest ecosystems and management techniques, with the aim of defining the best practices for the sustainability and profitability of fungal resources.

Although the best practices necessary for truffle (*Tuber* spp.) cultivation are well established (e.g., Bonet et al., 2009; Giovannetti et al., 2010; Reyna and Garcia-Barreda, 2014), this is not the case for epigeous macromycetes, some of which are also commercially important. Most of the economically valuable species are mycorrhizal fungi (e.g. *Boletus* spp., *Lactarius* spp., *Cantharellus* spp. and *Tricholoma* spp.). However, some saprotrophic (e.g. *Morchella* spp., *Agaricus* spp. and *Macrolepiota* spp.) and parasitic (e.g. *Armillaria* spp.) species may also be important for local economies (Table 1). Although an increasing number of studies have focused on evaluating the effects of silvicultural practices on fungal yield in recent years (e.g., Bonet et al., 2012; Lin et al., 2015), and some authors have proposed guidelines for fungal-oriented silviculture (Palahí et al., 2009; Pierangelo and Rolland, 2013; Bettini et al., 2016), the large number of potential variables influencing mushroom yields, and their interdependence, make the development of clear forest management recommendations rather challenging. Moreover, the existing studies are mostly local or regional and, hence, the scientific knowledge on this topic is rather scattered. Therefore, recommendations that may be useful for a specific area may not be suitable for sites with a different climate or forest stand structure, or if the highly valued edible mushroom species differ between regions according to differences in stakeholders’ preferences. In this sense, a systematic review of current knowledge about forest management practices that are able to increase mushroom yield may help to shed light on this complex issue and contribute to clarifying the state of the art as a basis for further research.

Based on these considerations, the aims of this paper are: (i) to review the current scientific literature regarding the effects of forest management on the yield of wild epigeous mushrooms, with a