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Productivity of ectomycorrhizal and selected edible saprotrophic fungi in pine forests of the pre-Pyrenees mountains, Spain: Predictive equations for forest management of mycological resources

J. Martínez de Aragón [a], J.A. Bonet [a], C.R. Fischer [a,*], C. Colinas [a,b,1]

[a] Centre Tecnològic Forestal de Catalunya, Pujada del seminari, s/n, E-25280 Solsona, Spain
[b] Departament de Producció Vegetal i Ciència Forestal, Universitat de Lleida, Av. Rovira Roure, 191, E-25198 Lleida, Spain

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Abstract

Edible and medicinal fungi have become increasingly important non-wood forest products in Spanish forests. Annual mushroom collections increase the economic value of forests and provide income to local collectors and marketers. Most of the species are ectomycorrhizal fungi that are essential for seedling establishment and long-term nutrition of the trees. Due to the economic depression in the local wood markets of the Pyrenees, forest managers are evaluating alternatives to timber management for these forests. Information on the biology and ecology of these fungi, especially on factors influencing their productivity, are needed to properly manage and enhance this natural resource. In 1997, 23 study plots of 400 m^2 were randomly placed in *Pinus nigra*, *Pinus sylvestris* and *Pinus halepensis* forests of Solsonés County, Catalonia, Spain, to monitor the production of ectomycorrhizal and edible forest fungi in relation to climate and forest stand variables. The 5-year inventory (1997 through 2001) included weekly sporocarp collections from September through December to estimate the annual county production and to examine production according to forest species, edibility and commercial status. Annual county sporocarp production was 29.4 kg ha^{-1}, of which 6.2 kg ha^{-1} are edible marketed species and 5.4 kg ha^{-1} are edible non-marketed species. Regression analysis of climate and forest stand variables reveal significant correlations with sporocarp production data. The best climate equation ($R^2 = 0.66$; $P < 0.001$) for annual sporocarp estimation was based on the difference between monthly mean precipitation and accumulated monthly mean evapotranspiration for the months of September and October, and the monthly mean minimum soil temperature in August. Stand age was not a good explicative variable for total sporocarp production, and was negatively correlated ($R^2 = 0.23$; $P < 0.021$) with production of edible species.

Keywords: Non-wood forest products; Adaptive silviculture; Edible mushrooms; Ectomycorrhizal fungi

1. Introduction

Forest owners in the Spanish Pyrenees have traditionally managed their forests almost exclusively for the production of wood. This practice, combined with the drop in wood prices in the past few decades, the shortage of manual labour, the decreased market for small diameter timber and the high costs of wood transportation has resulted in a serious decrease in the economic viability of the forestry sector (Mogas et al., 2005). A direct consequence of this loss has been the gradual decrease in the rural population (Aubarell et al., 1999), especially in mountainous areas. This decrease has very negative consequences for rural areas over the mid-to-long-term as the land-use mosaic created over centuries by diverse human activities disappears, increasing the risk of large forest fires (Domínguez et al., 2000).

Concurrent with the economic crisis in the wood products sector, mushroom gathering has become an increasingly popular recreation activity in the extensive forested and mountainous regions of Catalonia, NE Spain. In response to this rising interest, forest landowners and rural families are beginning to appreciate wild mushrooms not only as a leisure pursuit but also as an important economic resource. Income from forest fungi has been shown to equal or surpass profits gained through wood production (Martín-Pinto et al., 2006).

* Corresponding author. Tel.: +34 973 481 752; fax: +34 973 481 392.
E-mail addresses: mtzda@ctfc.es (J. Martínez de Aragón), jantonio.bonet@ctfc.es (J.A. Bonet), christine.fischer@ctfc.es (C.R. Fischer), carlos.colinas@pvcf.udl.es (C. Colinas).
[1] Tel.: +34 973 702 845; fax: +34 973 238 264.

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With a high market value and consumer demand (Cervera and Colinas, 1997) and a consistently strong recreational and tourist draw, forest fungi have become strategic in the conservation of rural populations and in the preservation and management of the forest environment (Pilz et al., 1998). However the mycological resources as well as other non-wood forest products are only recently becoming part of forest planning (Pilz et al., 1999; Díaz Balteiro et al., 2003).

Unlike wood production, mushroom production is characterized by great variability in the annual yield, a perishable product that requires timely collection and marketing strategies, and challenges in monitoring ephemeral fruit bodies (Vogt et al., 1992). These characteristics, combined with the limited knowledge regarding the effects of silvicultural treatments on fungal populations, make it extremely difficult for most forest managers to integrate mushroom production with wood production in management programs.

Predictive equations of forest mushroom yields are quite complex given the dynamics that influence ectomycorrhizal fungal communities. Numerous interactive factors come into play, before and during the autumn fruiting period, including environmental (rainfall, air and soil temperatures, evapotranspiration, relative humidity, and water deficits or excesses), silvicultural (tree species, stand age, density and distribution, canopy cover), ecological (community composition, competitive interactions, reproductive strategies), landscape (altitude, aspect, slope) and anthropogenic (timber removal, controlled burns, wildlife management, grazing, introduced species).

The forest tree species, which is host to associated fungal symbionts, influences the fungal community and fungal species richness through host specificity (Molina et al., 1992). Each host tree species can only form an ectomycorrhizal symbiosis with a recognized group of fungal species. Therefore the composition of ectomycorrhizal fungi is limited by the range of fungal symbionts recognized by a given host tree under the existing ecological conditions, and the diversity of host trees present in the forest stand. Forest age also has an effect upon succession, diversity and production of certain forest fungi (Kalamees and Silver, 1988; Smith et al., 2002; Bonet et al., 2004), and aspect has been shown to influence habitat for some species (Bonet et al., 2004).

Human intervention has played a significant role because forest management tools (clearings, pruning, species selection, fire, fertilization) can modify density, canopy cover, primary productivity, basal area, understory plant communities, soil conditions and soil microbial communities. These modifications in turn alter microclimates responsible for the succession and fruiting of numerous fungal species (Ohenoja, 1988; Fernández de Ana et al., 1989; Termorshuizen, 1993; Egli and Ayer, 1997; Hernández and Fernández, 1998).

There is growing recognition among foresters that mushrooms are valuable non-wood forest products and management guidelines are needed for mycological resources. The objectives of this study are to: (1) provide an inventory of species richness and productivity of ectomycorrhizal and edible forest fungi in *Pinus nigra*, *Pinus sylvestris* and *Pinus halepensis* forests of Solsonés County; (2) identify correlations between mushroom productivity and selected forest stand characteristics and climate factors; and to (3) design predictive equations based on these relationships which can be used as guidelines for forest managers who wish to include both wood and forest fungi in management practices.

2. Material and methods

2.1. Study sites

This study was carried out in the county of Solsonés, Lleida, Spain, in the mountainous pre-Pyrenees region of Catalonia. It is a forested county that has experienced the economic crisis associated with changes in the globalization of the wood market.

This county has a particularly steep altitudinal gradient, with elevations ranging from 400 m in the south to 2400 m in the north. The south has a somewhat Mediterranean climate, with an average of 600 mm annual precipitation, mostly in spring and autumn. Annual precipitation in the north reaches 1000 mm and, in contrast to the south, is evenly distributed throughout the year.

At the beginning of this study (1997), the county of Solsonés (100,000 ha) had 65,300 ha of forests, of which 11,000 ha were destroyed in a catastrophic fire in 1998. Pine forests (*P. nigra* Arnold., *P. sylvestris* L. and *P. halepensis* Mill), managed for lumber production, are the dominant (95%) forest cover. Holm oak (*Quercus ilex* L.), downy oak (*Quercus pubescens* Wild.) and Lusitanian oak (*Quercus faginea* Lamk) make up the rest and are scattered within the pine forests as individuals or small patches.

From the 579 sites included in the 1992 Forest Ecological Inventory of Catalonia carried out by Centre de Recerca Ecològica i Aplicacions Forestals (CREAF, 1992), our sampling plots were chosen randomly from nearly pure, even-aged stands that were characterized by >80% of the trees belonging to a single species: *P. nigra*, *P. sylvestris* or *P. halepensis*.

2.2. Distribution of sampling plots

The study is based on a 5-year autumn sampling of randomly selected forest plots, stratified in three levels corresponding to the three pine species dominant in the area. These plots were distributed throughout the county in numbers proportional to the area occupied by each species of tree with an initial total of 34. Plots destroyed by the fire were eliminated from the study leaving us a total of 23 sampling plots. *P. nigra* was represented by 11 plots, *P. sylvestris* by 7 plots and *P. halepensis* by 5 plots (Table 1).

Each plot was a 400 m^2 square (Salo, 1979; Ohenoja, 1984) marked off by visible posts at each corner to facilitate sampling (Kalamees and Silver, 1988). Each plot was further divided into four subplots of 100 m^2 (Vogt et al., 1983; Ohenoja and Koistinen, 1984; Dahlberg and Stenlid, 1994; Bonet et al., 2004). Subplot data were used to evaluate the effect of plot size on estimates of sporocarp production and species richness. By working with subplot data, we also reduced the total sample area, so the effect of a smaller plot size cannot be separated from the effect of a smaller sample area in this study.