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# Impact of forest management intensity on landscape-level mushroom productivity: A regional model-based scenario analysis

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ABSTRACT

The aim of this study was to predict the effect of forest management intensity on mushroom productivity at the landscape level by means of a model-based scenario analysis. The study area was Catalonia region, north-eastern Iberian Peninsula. Mushroom yield models were developed for the most common pine-dominated forest ecosystems. The models accounted for the effect of site and stand structure on mushroom occurrence and yield. The mushroom yield models and individual-tree growth models were used in continuous cover forestry simulation and optimization to assess the impact of alternative regional forest management intensity scenarios on landscape-level mushroom productivity. The baseline scenario was defined as the estimated current forest harvesting intensity in Catalonia (i.e., 25% of annual forest growth). The time frame was 30 yr. The current average productivity of valuable mushrooms is 14 kg ha$^{-1}$ yr$^{-1}$ (4600 tonnes yr$^{-1}$). Under the current forest management intensity, a loss of 220 tonnes yr$^{-1}$ (5%) in mushroom production at the regional level can be expected. In the absence of forest management, the loss in productivity can attain almost 500 tonnes yr$^{-1}$ (11%). With forest harvesting intensity similar to the average in Europe, an increase of 100 tonnes yr$^{-1}$ (2%) in mushroom production could be expected. If forest harvesting was equal to 100% of annual forest growth, an increase of 262 tonnes yr$^{-1}$ (6%) could be expected. Mushroom productivity increases with increasing forest management intensity. Low forest management intensities may result in a progressive reduction in mushroom yield. Intermediate management intensities would maintain the current mushroom productivity. Sustained yield harvesting policy would contribute to increasing mushroom productivity in continuous cover forestry.



## 1. Introduction

Wild mushrooms are important non-wood forest products all over the world. As food or condiment, they are often considered a delicacy and their nutritional value is comparable to many vegetables. Owing to their medicinal properties, they are also important for human health and they are often used as traditional medicine (Boa, 2004). In this regard, Catalonia (north-eastern Iberian Peninsula) represents a paradigmatic case of a long tradition of mushroom picking and trade. Hundreds of tonnes of edible forest mushrooms annually sold in local markets contribute to a significant economic activity of several million euros. The Central Market of Barcelona, the capital city of Catalonia, is the most important market of wild edible mushrooms in Spain (Voces et al., 2012). In the current context of low profitability of timber-oriented forestry arising from the high harvesting costs compared to the income from wood products, the economic benefit of mushroom harvesting can be clearly higher than the economic profit obtained from timber production (Alexander et al., 2002; Palahí et al., 2009). Furthermore, the deep-rooted tradition of mushroom picking for self-consumption gives additional value to wild mushrooms as a recreational and environmental service (Martínez de Aragón et al., 2011; Schulp et al., 2014).

Forest stand characteristics, coupled with the strong influence of climatic and site variables (e.g., precipitation, temperature and aspect), determine the productivity of wild mushrooms (Bonet et al., 2008, 2010). Stand basal area, stand age and dominant height have been found to have a significant effect on mushroom production (Bonet et al., 2012; Martínez-Peña et al., 2012). Although weather and site conditions cannot be controlled by forest managers, mushroom yield can be affected by means of forest

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management (Bonet et al., 2012; Egli et al., 2010; Pilz et al., 1999). It can be therefore expected that management intensity has an impact on mushroom productivity.

Forest management intensity can be described by the ratio between annual felling and annual volume increment (so-called felling rate). Sustainable forest management partly relies on the concept of maximum sustained yield, which implies that wood harvesting should be approximately equal to forest growth (Luckert and Williamson, 2005; Elbakidze et al., 2013; Helms, 1998). While the average felling rate in Europe is around 65% (Forest Europe et al., 2011), the estimated current wood harvesting in Catalonia represents only 20–30% of annual forest growth (Levers et al., 2014). A gradual decline of the forest sector has occurred in Catalonia during the last decades, which has resulted in a progressive abandonment and reduction of forest management practices and harvesting operations. If such a trend persists, the forests of the region might be increasingly unmanaged in the coming decades. On the other hand, utilization of forest biomass for bioenergy and new applications of forest products in emerging sectors arising from innovations in the forest industry may boost forest management in the future. Whatever the evolution of forest management intensity, it is likely to affect mushroom productivity, the economic value of forests (Pilz et al., 1999) and the socioeconomic activity based on mushroom picking.

The assessment of the impact of forest management on landscape-level mushroom productivity can be tackled from a modelling and simulation perspective. In combination with forest growth models for the simulation of stand dynamics, mushroom yield equations can be used to predict mushroom productivity under different stand structures and silvicultural regimes (Palahí et al., 2009). Mushroom yield models based on permanent sample plots have been previously fitted for Catalonia by Bonet et al. (2008, 2010). Since this sampling effort has continued over time and has been significantly expanded to additional plots and forest ecosystems (i.e., including mixed and pure stands), models based on new and improved data can bring deeper insight into the influence of forest stand structure and management on mushroom yield (Pilz and Molina, 2002). Although previous research has analyzed the effect of forest management on mushroom productivity at the stand level (Alexander et al., 2002; Palahí et al., 2009), so far no studies have dealt with the impact of forest management intensity at the landscape or regional level, which is crucial in large-scale forest policy making.

The aim of this study was to analyze alternative regional forest management intensity scenarios in relation to their impact on the landscape-level mushroom productivity based on new and improved mushroom yield models.

## 2. Material and methods

### 2.1. Modelling mushroom yield

Yield models were developed for the fresh mass of total, edible and marketed mushrooms based on data obtained from the weekly monitoring of permanent sample plots in stands representing most pine forest ecosystems found in Catalonia. The sampling started with the measurement of 24 plots between 1995 and 1997. Since then, new plots have gradually been established, the number of additional plots measured in 2012 being 83. In total, measurements have been done in 107 plots. The plots represent pure and mixed pine stands. The number of sample plots in pure *P. sylvestris*, *P. nigra*, *P. halepensis* and *P. pinaster* stands was 43, 14, 8 and 30, respectively. The number of plots in mixed *P. sylvestris*-*P. nigra* and *P. nigra*-*P. halepensis* stands was 7 and 5, respectively (Table 1).

The trees of the sample plots have been measured once or twice for diameter at breast height and height. To be able to relate annual mushroom yield to the stand structure in a given year, the stand characteristics were updated for each year using individual-tree growth models for pine stands in Catalonia (e.g., Palahí, 2002; Trasobares, 2003; Trasobares et al., 2004). Alternatively, linear interpolation was used in some plots where trees had been inventoried at two different measurement occasions with a few years difference.

Mixed-effects models, which can account for the spatial and temporal correlation among observations and can deal with unbalanced data (Pinheiro and Bates, 2000), were used to predict annual mushroom yield. This methodological choice is justified since the number of sample plots varied between forest ecosystem types and, furthermore, because mushroom yield data from permanent sample plots established in different pine ecosystems are expected to be spatially and temporally correlated. This is because stands belonging to a given forest ecosystem and sharing similar ecological conditions are more likely to present similar yields than stands from different forest types. Similarly, a given stand is more likely to present similar mushroom productions over time.

An additional feature of mushroom yield data is the high occurrence of "zero" production in many sample plots over time arising from small plot sizes and the stochasticity of sporocarp emergence. Thus, the stochastic nature of mushroom yield was taken into account by using a two-stage modelling approach that accounts for two separate states (Hamilton and Brickell, 1983; Vanclay, 1992). The first stage aimed at predicting the probability of occurrence of mushroom production based on binomially distributed data (i.e., absence or presence) by means of mixed-effects logistic regression (Eq. (1)) using a logit link function (Eq. (2)). The second stage involved linear mixed-effects modelling aiming at predicting mushroom yield in log scale conditional on the occurrence of sporocarp emergence in the first stage (Eq. (3)). Snowdon's bias correction factor (Snowdon, 1991) was used to correct the predictions for the back-transformation bias to the original scale. Final mushroom yield estimations were computed as the product of the probability of occurrence and the conditional yield estimate (Eq. (4)):

$$p(y=1|x) = \pi(x) = \frac{1}{1+e^{-[(\beta_0+b_0)+(\beta+b)x_1]}} \tag{1}$$

$$g(x) = \log\left[\frac{\pi(x)}{1-\pi(x)}\right] = (\beta_0+b_0)+(\beta_n+b_n)x_1 \tag{2}$$

$$\ln(yield_c) = (\beta_{n+1}+b_{n+1})+(\beta_k+b_k)x_2+\varepsilon \tag{3}$$

$$yield = \pi(x)\times CF\times e^{\ln(yield_c)} \tag{4}$$

where $p(y=1|x)$ is probability of total, edible or marketed mushroom occurrence of stand $i$ in pine ecosystem $j$ and year $k$, $yield_c$ is total, edible or marketed mushroom yield conditional on mushroom occurrence, $yield$ is total, edible or marketed mushroom yield (kg ha$^{-1}$ yr$^{-1}$), $\beta$ denotes fixed-effects model parameters, $b$ denotes random effects, $x_1$ and $x_2$ are vectors of independent variables, $CF$ is bias correction factor and $\varepsilon$ is residual following a normal distribution with mean equal to zero and variance equal to $\sigma^2$ .

Model evaluation and selection was based on fitting statistics, i.e., statistical significance of model parameters ($t$-value > 2, $p$-value < 0.05), residual standard error and likelihood-ratio tests, as well as on the agreement with current scientific knowledge on forest and mushroom ecology.