Effect of the Inclusion of Mushroom Values on the Optimal Management of Even-Aged Pine Stands of Catalonia

Marc Palahí, Timo Pukkala, José Antonio Bonet, Carlos Colinas, Christine R. Fischer, and Juan R. Martínez de Aragón

Abstract: Mushrooms are an important product of the pine stands of the Central Pyrenees of Catalonia. In places where the microclimate is reasonably moist, the value of mushrooms may be clearly higher than the value of timber production. This study examines the optimal economic management for both timber and mushrooms in even-aged Scots pine and Black pine stands in Catalonia. Empirical mushroom yield models were integrated in a stand growth simulator, which was linked with an optimization algorithm to find the optimal management schedule for Pinus sylvestris and Pinus nigra stands on different sites and with different mushroom prices. The results showed that on sites where the potential mushroom yield is high, mushrooms should be taken into account in stand management. Thinnings treatments, which usually are unprofitable, were included in the optimal management schedule when mushroom production was included in the analysis. Although thinnings have a negative short-term effect on mushroom yields, their long-term effect is often positive because they reduce stand density to a level that is favorable for mushrooms. At elevations that are suitable for P. sylvestris (900–1,500 m above sea level), the soil expectation value (SEV) of mushroom yields was commonly 4–10 times higher than the SEV of timber production. At somewhat lower elevations, where P. nigra dominates, the effect of mushrooms on the optimal stand management was smaller because mushroom yields are typically lower in P. nigra stands. FOR. SCI. 55(6):503–511.

Keywords: Pinus sylvestris, Pinus nigra, Scots pine, Black pine, joint production

Wild edible and medicinal mushrooms represent an important nonwood forest product worldwide (Boa 2004) to the extent that the commercial value of forest fungi may equal or even surpass the value of timber (Oria-de-Rueda and Martínez de Azagra 1991, Arnolds 1995, Alexander et al. 2002). In addition, mushroom picking has become one of the most important forest recreational activities in many parts of Europe (Lund et al. 1998, Martínez de Aragón 2005, Mogas et al. 2005, Martínez de Aragón et al. 2007), as well as in North and Central America (Zamora-Martinez and Nieto de Pascual-Pola 1995, Pilz and Molina 2002, Garibay-Orijel et al. 2006). In the last decade, recreational and commercial collections of forest fungi have become increasingly important in several regions of Spain, such as Catalonia. Recent inventories of wild mushrooms in Catalonia report productions of approximately 60 kg ha⁻¹ fresh weight (Martínez de Aragón et al. 2007) of which 46% are nonedible species, 29% are marketed edible species, and the other 25% are edible but nonmarketed species (Bonet et al. 2004). Within the marketed species, the Lactarius deliciosus group that also includes Lactarius sanguifluus, Lactarius semisanguifluus, and Lactarius vinosus are highly valued species sold under the generic name of rovelló. Annual revenue from 478 metric tons of L. deliciosus sold in the central Barcelona market (Mercabarna) is estimated at 1.5–2 million € (Bonet et al. 2009), which represents more than half of the total mushroom sales from this market. The marketed Lactarius group is highly profitable in other regions of Spain where it has been introduced with Pinus sylvestris reforestation (Bonet et al. 2009). When mushroom picking is a significant economic activity or forest resource, the effect of alternative management options on mushroom yields should be included in forest management and planning. Furthermore, the value of mushroom yields needs to be considered in the financial analysis of forest management. This value can vary widely, depending on the value of the forest trees and the economic importance of the fungal species (Alexander et al. 2002).

The inclusion of mushroom yields as an explicit objective in forest management and planning requires models for assessing, in a quantitative way, the production of mushrooms in different forest stands and management schedules. Such models can be developed with statistical methods, using empirical data on mushroom production and forest stand characteristics (Bonet et al. 2008, 2009). Mushroom production also depends on weather conditions such as timing and quantity of rainfall, but such variables are not
equally useful in forest planning because they cannot be accurately predicted beyond a few weeks. Once predictive models are developed, they can be included in forest simulators to provide quantitative information on mushroom production and its economic effects in alternative forest management schedules.

Determining the optimal management for maximizing the profitability of joint production of timber and mushrooms is a complex problem. Many decision variables such as the periodicity and intensity of thinnings and time of regeneration cuts may affect both timber and mushroom production. Solving such a problem requires, besides a simulator to predict timber and mushroom yields in alternative stand management schedules, optimization techniques to search for such a combination of decision variables that maximize the profitability of the production system. Dynamic programming and nonlinear programming have been widely used for finding optimal silvicultural regimens. Dynamic programming has proved to be successful in solving problems based on stand-level growth models, but there are some shortcomings when individual tree-level growth models are used (Valsta 1993). Nonlinear programming methods with individual-tree models have gained considerable popularity in stand management optimization (Roise 1986, Valsta 1987, 1990, 1992, Möykkynen et al. 2000, Palahí and Pukkala 2003, Trasobares and Pukkala 2004b).

In this study we used simulation and optimization tools to examine the effect of mushroom production on the optimal management of Scots pine (Pinus sylvestris L.) and Black pine (Pinus nigra Arn.) stands in Catalonia when maximizing soil expectation value (SEV). The recent mushroom yield models of Bonet et al. (2009) were programmed in an existing simulator. The effect of mushroom production on the optimal stand management was analyzed with varying mushroom prices and site conditions (elevation, aspect, and slope). The sensitivity of the results to the impact of thinning treatment on mushroom production was also analyzed.

Materials and Methods

Simulation of Forest Growth and Mushroom Yield

Stand growth was simulated using the models for P. sylvestris and P. nigra developed by Trasobares and Pukkala (2004a), which consist of individual tree diameter growth, height models, and survival functions. Annual mushroom yields were predicted with the mushroom yield models of Bonet et al. (2009), based on 45 permanent mushroom plots measured during 3–6 years. Such plots were established to estimate the production and diversity of forest fungi, primarily the large fleshy fruticules of ectomycorrhizal fungi from P. sylvestris and P. nigra and Pinus halepensis stands. The plots included approximately 220 taxa, with the most important production or economic relevance from the following genera: Lactarius, Tricholoma, Hebeloma, Hygrophorus, Armillaria, Hydnum, Suillus, and Chroogomphus. A complete species inventory can be found in Martínez de Aragón et al. (2007).

The mushroom models used (Equations 1, 2 and 3, 4) predict both the total yield of edible mushrooms as well as the yield of marketed mushrooms as a function of stand and site characteristics. The group “edible mushroom” includes edible marketed mushrooms as well as mushrooms that are categorized as edible but are not yet marketed in Catalonia. The group “marketed mushrooms” includes all edible mushrooms that are currently marketed in Catalonia.

Edible mushrooms

\[
\text{Edible} = \exp(-26.232 + 4.2742 \times \ln(G) - 2.376 \times \sqrt{G} + 3.824 \times \ln(Ele) + 0.435 \times \ln(Slo + 1) \\
\times \cos(\text{Asp}) + \text{PF}_{\text{Edible}} \times 1.926
\]

\[
\text{PF}_{\text{Edible}} = 0.115 + 0.405 \times \text{planted} \times 0.003
\times \text{Slo}^{1.5} + 0.662 \times \text{sylvestris},
\]

Marketed mushrooms

\[
\text{Marketed} = \exp(-28.362 + 2.634 \times \ln(G) - 1.338 \times \sqrt{G} + 3.956 \times \ln(Ele) + 0.219 \times \ln(Slo + 1) \\
\times \cos(\text{Asp}) + \text{PF}_{\text{Marketed}} \times 3.915
\]

\[
\text{PF}_{\text{Marketed}} = 0.275 + 0.985 \times \text{planted} \times 0.008
\times \text{Slo}^{1.5} + 1.628 \times \text{sylvestris},
\]

where Edible and Marketed are the annual mushroom productions of edible and marketed species in kg per ha, G is stand basal area (m² ha⁻¹), Asp is aspect (rads), Slo is slope (%; i.e., 45° is equal to 100%), Ele is elevation (m above sea level), PF_{Edible} and PF_{Marketed} are plot factors to calibrate the model for a certain stand or plot. Within the plot factor models, planted is a dummy whose value is equal to 1 for planted P. sylvestris stands and otherwise 0, and sylvestris is a dummy variable whose value is equal to 1 for P. sylvestris stands and 0 for P. nigra. The two transformations of stand basal area, ln(G) and √G, together describe the ascending-descending pattern of the relationship between G and mushroom production, which achieves its maximum at stand basal area of 15–20 m² ha⁻¹. Bonet et al. (2009) proposed that such a pattern may be explained by the fact that Catalan pine stands reach their peak growth rate at this basal area. This relationship between peak mushroom production and peak stand growth rate is in accordance with the work of Nara et al. (2003), who demonstrated that formation of mycorrhizal sporocarps was strongly correlated with the growth and photosynthetic rate of the host trees.

The effects of site on mushroom yields are included in the models by different geo-topographical variables: elevation, slope, and aspect, which are known to affect moisture; temperature; light; and other chemical and physical properties of the site. Predictor ln(Slo + 1) cos(Asp) explains the increasing effect of aspect on steeper slopes. The logarithmic transformation of elevation explains the positive effect of elevation on mushroom production. In addition, the plot factor equations include the effect of slope (the steeper the
slopes, the lower the mushroom yields), stand establishment method, and dominant species. *P. syulvestris*-dominated stands produce higher mushroom yields than *P. nigra*-dominated stands. In addition, the models predict higher mushroom yields in naturally regenerated *P. syulvestris* stands than in planted *P. syulvestris* stands.

Similarly to Alexander et al. (2002), the predictions of the mushroom yield models were multiplied by 0.5 because it was assumed that only 50% of the total yield of the season is actually harvested. The yield of edible nonmarketed mushrooms was calculated by subtracting the prediction of marketed mushroom yield (Equations 3 and 4) from the total production of edible mushrooms (Equations 1 and 2). The above equations do not account for the immediate negative effect of thinning on mushroom yields, which is due to an abrupt change in microclimate and the loss of tree hosts that provide carbohydrates and metabolites to ectomycorrhizal fungi. Pilz et al. (2006) found that forest thinning significantly reduced fruit body production of *Chanterelle* in the first year after light and heavy thinning treatments, but this effect disappeared in 2–6 years. Pukkala et al. (2002), who studied the thinning response of Scots pine, found that trees experienced thinning stress for 2–3 years after thinning, most probably because of an instant change in growing conditions. Such a thinning reaction in tree growth may partly explain the reductions in mushroom yields after thinning procedures.

Because no exact empirical information about the effect of thinning on mushroom yields was available, the following thinning reduction was assumed (Figure 1): the year after a thinning the mushroom production was reduced proportionally to the basal area removed, e.g., if the thinning removed 50% of the basal area, the mushroom production was reduced 50% in the following year. Then, the thinning effect decreased linearly until it was over in 10 years (Figure 1). This thinning effect was used as a multiplier of the mushroom yield model. Therefore, if thinning reduces stand basal area to a level that is optimal for mushroom production, the total effect of thinning may become positive within 1–3 years.

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**Initial Stands**

Two inventory plots were used as starting points for stand simulation (Table 1). The plots represent young even-aged stands of *P. syulvestris* and *P. nigra* on sites with medium fertility in central Catalonia. A precommercial thinning had been conducted in both stands. These plots were located in central Catalonia, the area for which Bonet et al. (2009) developed the mushroom yield models.

**Economic Data**

Felling and forwarding costs (from forest to road) were based on the published tariff by Diputació de Barcelona (2006). The tabulated tariff values were smoothed to have a model for the felling costs and another model for the forwarding costs as a function of tree size (Figure 2):

\[
\text{felling} = \exp(3.406 - 0.568 \ln(d)), \quad (5)
\]

\[
\text{forwarding} = \exp(7.225 - 0.992 \sqrt{d}), \quad (6)
\]

where felling and forwarding are felling and forwarding costs, respectively, in € m⁻³ and *d* is breast height diameter (dbh) in cm. In addition, a cost of 900 € ha⁻¹ corresponding to a precommercial thinning was assumed to take place 24 years after stand establishment based on the study of Solano et al. (2007). No regeneration costs were assumed at the beginning of the rotation because natural regeneration was used.

A timber price model was developed based on tabulated price values published by Consorci Forestal de Catalunya (2006). The following stumpage price model was developed (Figure 2):

\[
\text{price} = d^2/(1.69 + 0.52d + 0.019d^2), \quad (7)
\]

where price is stumpage timber price (€ m⁻³) and *d* is dbh (cm) of the tree. Mushroom revenues were calculated by assuming an average price of marketed mushrooms in the local markets of Central Catalonia of 5€ kg⁻¹, and a 0 € kg⁻¹ price was assumed for edible mushrooms that are currently not marketed (Martínez de Aragón 2005). Other prices were also used when the effect of price was analyzed.

**Table 1. Summary of the characteristics of the two plots used in the study**

<table>
<thead>
<tr>
<th></th>
<th><em>P. syulvestris</em> plot</th>
<th><em>P. nigra</em> plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td><em>N</em>&lt;sub&gt;tree&lt;/sub&gt; (trees ha⁻¹)</td>
<td>1,625</td>
<td>2,228</td>
</tr>
<tr>
<td><em>G</em> (m² ha⁻¹)</td>
<td>10.2</td>
<td>20.8</td>
</tr>
<tr>
<td><em>D</em>&lt;sub&gt;max&lt;/sub&gt; (cm)</td>
<td>4.0</td>
<td>5.5</td>
</tr>
<tr>
<td><em>D</em>&lt;sub&gt;g&lt;/sub&gt; (cm)</td>
<td>9.7</td>
<td>11.6</td>
</tr>
<tr>
<td><em>D</em>&lt;sub&gt;max&lt;/sub&gt; (cm)</td>
<td>14.0</td>
<td>15.5</td>
</tr>
<tr>
<td>Elevation (m)</td>
<td>1,200</td>
<td>900</td>
</tr>
<tr>
<td>Aspect</td>
<td>East</td>
<td>North</td>
</tr>
<tr>
<td>Slope (%)</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

*N*, number of trees per hectare; *G*, stand basal area; *D*<sub>max</sub>, minimum diameter; *D*<sub>g</sub>, basal-area weighted mean diameter; *D*<sub>max</sub>, maximum diameter.
The present value of net incomes (NPV) derived from mushroom production is defined as the net present value of all future net incomes. The NPV of an infinite series of future harvests is referred to as the soil expectation value (SEV) and can be computed as

$$NPV = \sum_{i=0}^{T} \frac{R_i - C_i}{(1+i)^t} + \sum_{i=0}^{T} \frac{M_i}{(1+i)^t},$$

where $M_i$ is the net income from mushrooms, $R_i$ is timber revenues, $C_i$ is timber production costs, $i$ is the discounting rate, $t$ is the year of the operation, and $T$ is the rotation age.

The NPV of an infinite series of future harvests is referred to as the soil expectation value (SEV) and can be computed from

$$SEV = \frac{NPV}{1 - 1/(1+i)^t}.$$
maximized with good mushroom price. It is also noteworthy
that even with the minimum price of 5 € kg\(^{-1}\) for marketed
mushrooms, the SEV of mushroom production was 4.3
times the SEV of timber production.

The effect of valuing mushrooms on optimal manage-
ment was smaller in the *P. nigra* stand in which mushroom
yields were much lower than in the *P. sylvestris* stand.
When only marketed mushrooms were valued, the only
effect was shortening optimal rotation length as a function
of improving price of mushrooms (Table 2; Figure 4). Thinning
treatments were never included in the optimal
management schedule until edible nonmarketed mushrooms
were assumed to be worth 5 € kg\(^{-1}\), when the optimal
management changed drastically: thinnings were used to

Table 2. Effect of the price of edible mushrooms on the optimal management schedule of a *P. sylvestris* and a *P. nigra* stand

<table>
<thead>
<tr>
<th>Mushroom price (€ kg(^{-1})) for marketed/nonmarketed mushrooms</th>
<th>0/0</th>
<th>5/0</th>
<th>10/0</th>
<th>10/5</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. sylvestris</em> (1,200 m, east)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEV (€ ha(^{-1}))</td>
<td>432</td>
<td>2,022</td>
<td>3,704</td>
<td>6,461</td>
</tr>
<tr>
<td>SEV timber (€ ha(^{-1}))</td>
<td>432</td>
<td>385</td>
<td>193</td>
<td>−267</td>
</tr>
<tr>
<td>SEV mushroom (€ ha(^{-1}))</td>
<td>0</td>
<td>1,637</td>
<td>3,511</td>
<td>6,728</td>
</tr>
<tr>
<td>Rotation length (years)</td>
<td>105</td>
<td>95</td>
<td>107</td>
<td>121</td>
</tr>
<tr>
<td>Wood production (m(^3) ha(^{-1}) a(^{-1}))</td>
<td>3.6</td>
<td>3.7</td>
<td>3.4</td>
<td>2.9</td>
</tr>
<tr>
<td>Mushroom harvest (kg ha(^{-1}) a(^{-1}))</td>
<td>5.6</td>
<td>5.9</td>
<td>6.9</td>
<td>20.3 (7.7)</td>
</tr>
<tr>
<td><em>P. nigra</em> (900 m, north)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEV (€ ha(^{-1}))</td>
<td>−31</td>
<td>367</td>
<td>761</td>
<td>3,131</td>
</tr>
<tr>
<td>SEV timber (€ ha(^{-1}))</td>
<td>−31</td>
<td>−42</td>
<td>−54</td>
<td>−742</td>
</tr>
<tr>
<td>SEV mushroom (€ ha(^{-1}))</td>
<td>0</td>
<td>409</td>
<td>815</td>
<td>3,873</td>
</tr>
<tr>
<td>Rotation length (years)</td>
<td>135.0</td>
<td>130.0</td>
<td>125.1</td>
<td>205.5</td>
</tr>
<tr>
<td>Wood production (m(^3) ha(^{-1}) a(^{-1}))</td>
<td>3.2</td>
<td>3.3</td>
<td>3.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Mushroom harvest (kg ha(^{-1}) a(^{-1}))</td>
<td>1.38</td>
<td>1.45</td>
<td>1.48</td>
<td>19.2 (2.5)</td>
</tr>
</tbody>
</table>

Slope is assumed to be 20%. When the price is 10€ kg\(^{-1}\) for marketed mushrooms and 5€ kg\(^{-1}\) for nonmarketed (price combination 10/5), the mushroom harvest includes also nonmarketed mushrooms (the harvest of marketed mushrooms is shown in parenthesis).

Figure 3. Effect of mushroom price in *P. sylvestris*. Elevation is 1,200 m, aspect is east, and slope is 20%.

Figure 4. Effect of mushroom price in *P. nigra*. Elevation is 900 m, aspect is north, and slope is 20%.
maintain stand basal area continuously at a level that is required for maximal mushroom production. The optimization results show that timber production would not be profitable in this stand with the timber prices and management costs used. However, mushrooms would make the forestry profitable, even early thinnings if the price of mushrooms is sufficient, equal to 10 € kg\(^{-1}\) for marketed mushrooms and 5 € kg\(^{-1}\) for other edible mushrooms.

**Effect of Site Variables: Aspect, Elevation, and Slope**

According to the models of Bonet et al. (2009), mushroom yields are the highest on slopes with northern aspects and lowest on slopes with southern aspects. This observation was reflected in the optimization results so that the SEV, when both timber and mushroom production were included, was three times higher on the northern than on the southern aspect (Table 3). Aspect also affected optimal forest management so that cuttings were earlier or heavier on the northern aspect with the consequence that the average stand basal area during the rotation was lowest on the northern aspect and highest on the southern aspect, presumably because it is more important to reduce stand basal area on northern slopes where mushroom production is a more important factor than on the other aspects. The primary aim of the very heavy thinning at 70 years on the northern aspect is to increase mushroom production.

Increasing elevation from 900 to 1,500 m has a similar effect as moving from southern to northern aspects (Table 3; Figure 5). At 1,500 m, the very heavy thinning at 60 years greatly increased mushroom yields for three to four decades, making the treatment profitable although it would be non-profitable from the timber production point of view. At lower elevations, where mushrooms play a smaller role, all cuttings were conducted near the end of rotation when harvesting is less costly. At 900 m, the SEV of mushroom production was 1.4 times the SEV of timber production, but at 1,500 m the SEV coming from mushrooms was as much as 16 times higher than the SEV of timber production.

The mushroom yields of the optimal management schedule were similar on 0 and 20% slopes but clearly lower on 40% slopes (Table 3). From the SEV values of Table 3 it seems that on steeper slopes, where mushroom production is small, both mushroom and timber production have an impact on the optimal management schedule. The effect of mushrooms becomes clearer on less steep slopes for which the optimal management schedule includes a very heavy thinning at 55–70 years. This schedule greatly increases the mushroom yield for the rest of the rotation. The decreasing contribution of mushrooms to the total SEV on steeper slopes occurs partly because mushroom productivity decreases with increasing slope and partly because the effect of mushrooms on optimal stand management decreases.

**Effect of Thinning Reaction**

Varying the duration of the thinning effect from 0 to 20 years had practically no effect on the optimal management of the *P. sylvestris* stand studied (Table 4). The SEV coming from mushroom production slowly decreased when the duration of the thinning effect increased. The share of mushroom production of the total SEV on steeper slopes decreases with increasing duration of the thinning effect. The mean annual mushroom harvest decreased from 6.5 to 5.7

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**Table 3. Effect of aspect (elevation of 1,200 m, and slope of 20%), elevation (eastern aspect and slope of 20%) and slope (elevation of 1,200 m and northern aspect) on the management of and yield of *P. sylvestris* with mushroom price of 5€ kg\(^{-1}\) (marketed mushrooms)**

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Elevation</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. sylvestris</em></td>
<td>900 m</td>
<td>0%</td>
</tr>
<tr>
<td>SEV (€ ha(^{-1}))</td>
<td>3,610</td>
<td>2,012</td>
</tr>
<tr>
<td>SEV timber (€ ha(^{-1}))</td>
<td>374</td>
<td>374</td>
</tr>
<tr>
<td>SEV mushroom (€ ha(^{-1}))</td>
<td>3,294</td>
<td>1,638</td>
</tr>
<tr>
<td>Mushroom harvest (kg ha(^{-1}) a(^{-1}))</td>
<td>13.0</td>
<td>6.1</td>
</tr>
</tbody>
</table>

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**Figure 5. Effect of elevation in *P. sylvestris*. Aspect is east, slope is 20%, and mushroom price is 5€ kg\(^{-1}\) for marketed and 0€ kg\(^{-1}\) for nonmarketed mushrooms.**

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kg ha\(^{-1}\). The sensitivity analysis shows that assumptions concerning the duration of the thinning reaction would only have a marginal impact on the results.

**Discussion**

Little work exists on the financial and management implications at the stand and forest levels when both timber and mushrooms are considered. One reason has been that the biology of mushrooms is not yet understood well enough to develop predictive yield models. Pilz et al. (1998, 1999) compared the value of timber versus mushrooms in Washington’s Olympic National forest (*Chantharellus* species) and South-Central Oregon (*Tricolloma magnumvivare*). Alexander et al. (2002), building on the analysis of Pilz et al. (1998, 1999), presented an analytical method to jointly evaluate the financial importance of timber and mushrooms by calculating the SEV separately for both products. In that study, the existing growth simulator developed by Curtis et al. (1981) and Wykoff et al. (1982) was used to predict timber production, and several mushroom studies were used to estimate the mushroom production levels for different forest types.

In our study we introduced two innovative aspects compared with previous studies: an empirical mushroom yield model (Bonet et al. 2009) was used to predict mushroom production in every year for different stand management schedules, and an optimization tool was linked with the simulator to maximize the profitability of joint production of timber and mushrooms. The method described in this article allows forestry decisionmakers to find the optimal values simultaneously for all the decision variables that describe a stand management schedule (timing and intensity of thinning and time to commence regenerative cuts) when both timber and mushroom are considered.

The predictions of mushroom models were multiplied by 0.5 to estimate the amount of harvested yield. This proportion is in accordance with the study of Alexander et al. (2002). The mushroom price (5 € kg\(^{-1}\)) corresponds to the average season prices of 1998–2002 in the local markets of Central Catalonia (Martínez de Aragón 2005). These prices are conservative, because prices can be up to 4 times higher in the Barcelona city markets. Rather low prices were used because mushroom harvesting costs were not considered. This strategy was justified because mushroom picking is a very important recreational activity, the value of which may equal or surpass the actual harvesting costs (Mogas et al. 2005). Moreover, when pickers are professionals, mushrooms are most probably sold in larger cities with a higher price, meaning that the net income would not be less than the one used in this study. To avoid an overestimation of mushroom production after thinnings and regenerative cuts, a negative thinning effect on mushroom production was assumed (Figure 1). This assumption is in accordance with the study of Pilz et al. (2006), who found a negative thinning effect lasting maximally 6 years in the production of *Chanterelle* in Douglas-fir stands in Oregon. Kropp and Albee (1996) showed that the thinning effect may vary among mushroom species, whereas Kranabetter and Kroeger (2001) demonstrated (in a 3-year thinning study) that partial cuttings could be conducted without much of a reduction in mushroom production. In any case, research on the effect of thinning treatment on mushroom production is required in Catalonia to improve the predictions of the empirical models developed by Bonet et al. (2009).

The forest stand simulation model used in this study (Trasobares and Pukkala 2004a) consisted of individual tree growth, height, and survival models that are based on 8,000 and 5,700 observations of *P. sylvestris* and *P. nigra*, respectively, collected in the national forest inventory of the same region (Catalonia) in which the mushroom plots are located. The tree growth models are based on a large and representative data set. They have been widely used in several studies (e.g., Trasobares and Pukkala, 2004b, González et al. 2005, Solano et al. 2007) and are currently used also in forestry practice by the public administration.

In this study we analyzed only two initial stand structures, one representing *P. sylvestris* and the other representing *P. nigra*. The stand structures are typical even-aged young stands of these species in central Catalonia. These two species (occupy an area of 267,000 ha in Catalonia, representing more than 25% of the forest area) were selected for the study because of their importance for timber production and mushroom harvesting and the availability of mushroom yield and tree growth models for both species. Therefore, the results of the study are specific for such tree species and mushroom species (see Materials and Methods) in Catalonia, as well as for the management systems currently used.

The results of this study showed that mushrooms produce more profit than timber in most *P. sylvestris* and *P. nigra* stands of central Catalonia (Tables 1–3). In *P. sylvestris* stands with good site conditions for mushrooms, the SEV of mushroom harvesting was sometimes 10 times higher than the SEV of timber production, whereas on poor sites it was commonly 2–3 times higher. In *P. nigra* stands mushroom yields changed a non-profitable situation into a profitable one, especially when currently non-marketed edible mushrooms were assumed to have market value (Table 2). Because of the low current timber prices and high timber harvesting costs in Central Catalonia (influenced by a complex topography), timber production on poor and average sites is not profitable or has a low profitability (Table 1). This situation has led to the abandonment of large areas of forest which in turns has aggravated the problem of forest fires. This study showed that when mushroom yields are

<table>
<thead>
<tr>
<th>Duration of thinning effect</th>
<th>SEV (€ ha(^{-1}))</th>
<th>SEV timber (€ ha(^{-1}))</th>
<th>SEV mushroom (€ ha(^{-1}))</th>
<th>Mushroom harvest (kg ha(^{-1}) a(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 years</td>
<td>2,183</td>
<td>389</td>
<td>1,749</td>
<td>6.5</td>
</tr>
<tr>
<td>5 years</td>
<td>2,083</td>
<td>389</td>
<td>1,694</td>
<td>6.2</td>
</tr>
<tr>
<td>10 years</td>
<td>2,022</td>
<td>385</td>
<td>1,637</td>
<td>5.9</td>
</tr>
<tr>
<td>20 years</td>
<td>2,011</td>
<td>389</td>
<td>1,622</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Table 4. Effect of the duration of thinning effect on the management and yield of *P. sylvestris* at 1,200 m elevation, northern aspect, and 20% slope when mushroom price is 5 € kg\(^{-1}\) (marketed mushrooms)
included in an economic analysis, optimal forest management should be oriented toward maximizing mushroom production, making thinnings profitable (Figures 3–5). This strategy would also decrease the risk of fire (González et al. 2005). The effect of mushroom yields on forest management and profitability of forestry should not be underestimated because many forests that are currently unmanaged in Catalonia and therefore are prone to serious fire damage (González et al. 2006) would be profitable to manage if mushrooms were taken into account. In stands distant from roads it may be optimal to thin the stand to increase mushroom production but not transport the felled trees to the road.

The effects of mushroom yields on forest management are greatest when mushroom prices are high (Table 2) and when site conditions (elevation, slope, and aspect) are favorable for mushroom production (Tables 2 and 3). The effect of mushrooms could be even enhanced in the future if edible mushrooms that are currently nonmarketed would be commercialized (Table 2; Figures 3–5). This would double the current average yield of marketed mushrooms and would at least double the profitability of forest management, having significant effects on the optimal forest management. Mushroom picking is the most recognized forest recreational activity (even without factoring in the value of mushrooms) in Catalonia, and Catalanian people are willing to pay more for such activity, approximately €6 per person and year (Mogas et al. 2005) than for other nonmarketed forest services (Mogas et al. 2005). However, forest owners in Catalonia capture little to nothing of the value of mushrooms or the value of such recreational activity. Although the Catalan forest law (Generalitat de Catalunya 1988) assigns the management and property rights on forests products (including mushrooms) to the forest owner, this right is not enforced in practice and mushroom pickers collect mushrooms without paying any fee to the forest owner. In some regions neighboring Catalonia, various initiatives to charge fees to mushroom pickers have been successfully implemented by applying a daily fixed fee to pickers, who may then collect mushrooms for personal consumption and receive guidance and explanations concerning the appropriate sites and mushroom species (Puig and Almanzor 2007).

Therefore, for the current situation in Catalonia, this study can be considered as maximizing the social (private + external) profitability (from timber and mushrooms), when the forest owners do not get the market value of mushrooms. However, there are several potential ways to use the financial information generated by the present study to design suitable Pigovian subsidies (Koskela et al. 2007) to encourage forest owners to manage their forests so as to maximize social benefits (social profitability). Pigovian subsidies can internalize the positive externality of increasing mushroom yield for social use into the forest owner’s utility function by giving him or her thinning subsidies to maintain stand basal areas that are optimal for mushroom production. The level of such subsidies should be based on the estimated difference between the marginal social benefit and the marginal private benefit of such activity.

Other means such as mushroom picking fees (see Alexander et al. 2002) or direct payments based on the total mushroom harvest could be implemented, and the property rights of forest owners could be enforced to mushrooms produced in their properties (through fencing, signing, or other means). For public and communal forests in which mushroom production is important, the results and methods presented in this study could be used directly to maximize the profitability of timber and mushroom production.

The results of this study should be understood in the context of the forest growth and mushroom yield models we used, which were based on data collected during the last 10 years in Catalonia. We anticipate that with climate change there will also be changes in mushroom production by species and by forest type. Therefore, this study and its results should be used with caution for long-term projections or analyses.

Literature Cited


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