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Mushroom Production as an Alternative for Rural Development in a Forested Mountainous Area

José A. BONET[1,2]*, José R. GONZÁLEZ-OLABARRIA[2], Juan MARTÍNEZ DE ARAGÓN[2]

1 Departament de Producció Vegetal i Ciència Forestal, Universitat de Lleida-Agrotecnio Center (UdL-Agrotecnio). Av. Rovira Roure, 191, E-25198, Lleida, Spain

2 Centre Tecnològic Forestal de Catalunya (CTFC-CEMFOR). Ctra. de St. Llorenç de Morunys km 2, E-25280, Solsona, Spain

**Corresponding author, e-mail: jantonio.bonet@pvcf.udl.cat; Tel.: +34 973 702 848; Fax: +34 973 480 431; Second author, e-mail: jr.gonzalez@ctfc.es; Third author, e-mail: mtzda@ctfc.es.*

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Abstract: Wild mushrooms are recognized as important non-wood forest products in mountainous ecosystems, but their real potential for generating rural economies has not been fully evaluated due to the difficulties in obtaining reliable productivity data, minimizing their true potential as contributor to rural economies. Mushroom yield models based on large data series from *Pinus* forest ecosystems in the region of Catalonia (Spain), combined with data from the Spanish National Forest Inventory allow us to estimate the potential mushroom productivity by forest ecosystems. The results of 24,500 tons/yr of mushrooms of which 16,300 tons are classified as edible and 7,900 tons are commonly marketed demonstrate the importance of mushroom productions in Catalonian pine forests, mostly located in mountainous areas where the development of agricultural activities is limited. Economic mushroom value is estimated at 48 million € for the edible mushroom and 32 million € for those corresponding to marketable yields, confirming the potential of this non-wood forest product. These production results and corresponding economic values provide a basis for the incorporation of wild mushrooms as significant non-wood forest products in the development of forest policies in mountainous areas.

Keywords: Non-wood forest products; Mushroom models; National Forest Inventory; Economic value; Mushroom potential estimation

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Introduction

The northern basin of the Mediterranean Sea has been characterized, during the second half of the past century, by the migration of rural population to urban areas. Such depopulation of rural areas has provoked an expansion of the natural forest vegetation following land abandonment (FAO 2012). The consequence of this dynamic has generated a continuous forest cover increasing the quantity of forest area and wood biomass by surface (ICONA 1993; DGCN 2003), especially in mountainous areas (Améztegui et al. 2010).

Nevertheless, the poor growth rates for timber and the depletion of the timber industry in a global economy context in those rural areas have generated a lack of forest management increasing the risk of wildfires and other related forest hazards (Gonzalez-Olabarria and Pukkala 2011). Consequently, the forest sector is looking to other options in addition to timber production to maintain the fragile equilibrium in these valuable ecosystems and to provide new complementary alternatives that allows the rural population to maintain a certain level of economic activity.

Non wood forest products (NWFP) provide an opportunity to complement the income from timber production, and in some cases are the most valuable forest product as documented in the mountainous areas as the Pyrenees (Palahí et al. 2009). Nevertheless, Merlo and Croitoru (2005) estimated that only 9% of the total economic value of Mediterranean forests is related to the non-timber forest products, probably due to the lack of inclusion of the recreational value of collecting activities. In practice, these products are more precisely considered a value than a real good. Consequently, NWFP are not usually taken into consideration by present forest and rural policies, with no implementation of real measures for their promotion and valuation.

However, in some areas of Spain an effort has been made during the last decades to bring out the real value of non-wood productions, with special focus on forest mushrooms. Mushroom inventories based on permanent plots were carried out by Oria de Rueda et al. (2010) in *P. pinaster* and *P. sylvestris* ecosystems in Central West Spain with cited productions of 295 and 100 kg/ha of edible mushrooms respectively, while Martínez-Peña et al. (2012b) reported yields of 100 kg/ha of edible fungi in *P. sylvestris* forests and Martínez de Aragón et al. (2007) observed total yields of around 30 kg/ha in *Pinus* sp. in the Catalonian region (Northeastern Spain) demonstrating the high mushroom productivity of the Spanish mountainous ecosystems. An already existing economic activity associated with mushroom picking (Martínez-Peña 2009; Cai et al. 2011; Voces et al. 2012), the increasing willingness by the pickers to pay for collector's license (Martínez de Aragón et al. 2011) and promising results associated with mycosilviculture (Bonet et al. 2012) point out the economic potential of an activity that requires from further promotion and regulation.

The use of modeling techniques based on large mushroom data sets and forest-stand characteristics developed during the last years has facilitated the identification of the most influential factors affecting mushroom productions (Calama et al. 2010; Bravo et al. 2012), some of them being linked to forest management (Bonet et al. 2008; 2010; 2012; Martínez-Peña et al. 2012a). These models can be applied to large forested areas with well-know stand characteristics and can provide large-scale baseline data of the mushroom productivity in the targeted forest. The Spanish National Forest Inventory (DGCN 2003) with well-described characteristics of 1 km × 1 km plots from forested areas is an excellent example for the generation of a baseline database. The application of the present models to the forestry inventory data provides an opportunity to obtain regional mushroom productivity maps with the consequent global quantification of the mushroom potential and estimating the real value of the mycological resource.

The aims of this study are to estimate the potential yield of the mycological resources of Catalonia in pine forest stands, and to estimate the potential revenues derived from mushroom production that can help in sustaining forest management in the forested mountainous areas. For these purposes we will integrate the latest knowledge about mushroom production modeling and extensive forest inventory data.

1 Material and Methods

1.1 Study area

The Spanish community of Catalonia is a mountainous area located in the northeast of the Iberian Peninsula, with a surface area of 32,106 km^2 with an altitude ranging from the sea level to the 3,143 m a.s.l. in the Pyrenean Mountains. The Pyrenees form a natural frontier between France and Spain, and also induce strong changes in climate and vegetation. Forests are the most abundant land cover in the montane and subalpine belts, between 1,200 and 2,200 m a.s.l. (Burriel et al. 2004). Forests in Catalonia are diverse in terms of composition, with over 100 tree species identified. Conifers and especially pines (*P. uncinata, P. sylvestris, P. nigra, P. halepensis, P. pinea* and *P. pinaster*) make-up the most abundant forest types (Figure 1). These pine species dominate more than 700,000 ha of forest, 60% of the forested area in Catalonia (Ibáñez 2004). The target forest region of our study, around 464,000 ha, is comprised of nearly-pure forests of *P. sylvestris, P. nigra, P. halepensis, P. pinea* and *P. pinaster*, where the basal area corresponding to the dominant species represents over 80% of the total basal area of the forest.

1.2 Methodology

In order to assess the potential productivity of pine forests of Catalonia as producer of wild mushrooms the following steps are required (Figure 2): first, to select models capable of predicting mushroom production per area unit (kg/ha) based on forest site characteristics; second, to identify forest areas with suitable mushroom production where predictions can be made running the selected mushroom yield models using data from these areas; third, to extrapolate the predicted mushroom productions from areas with similar forest conditions; fourth, to calculate the total mushroom production in the region according to the per area mushroom productions and the surface of the forest areas where such productions were extrapolated and fifth, assign a price to the edible and marketable mushrooms, calculating their total economic potential.

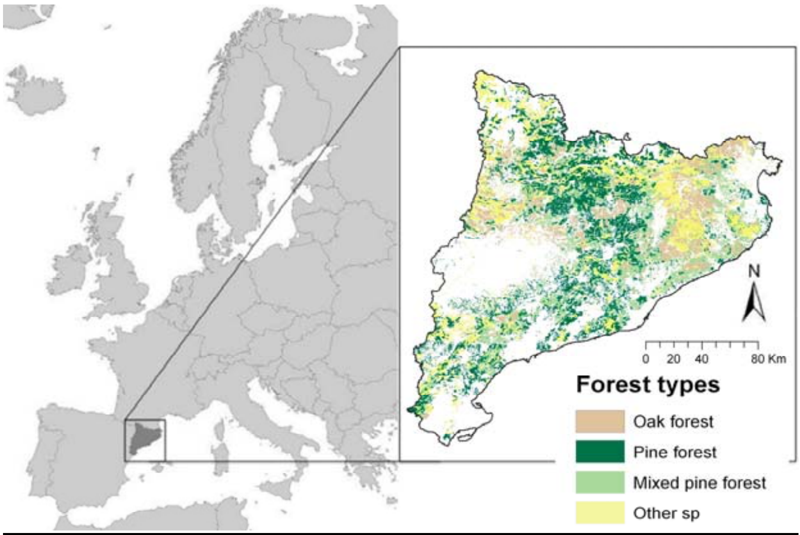

Figure 1 Distribution of the main forest types in Catalonia.

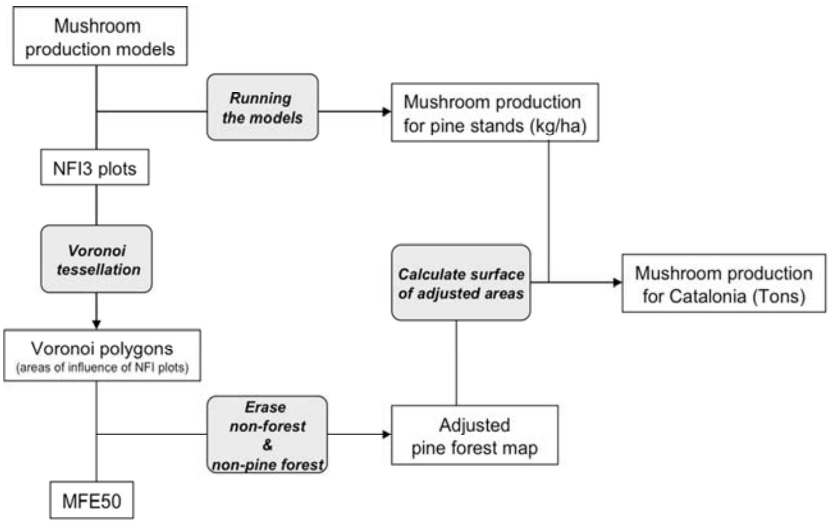

Figure 2 Flowchart of the steps followed in the present study.

1.2.1 Estimating the mushroom production (kg/ha) in pine forest

The mushroom yield models selected for the study were developed by Bonet et al. (2010). Those models are based on data coming from field inventories that entailed the measurement of mushroom production and forest characteristics in a total of 45 permanent plots located in the *P. sylvestris*, *P. nigra* and *P. halepensis* stands in Catalonia, Spain over 8 years (Bonet et al. 2010). In those plots, more than 600 fungal species were identified, of which around 400 are considered as mycorrhizal species. The classification of those species according with their edibility shows that around 30% are edible, and of them, 5% are usually sold in the markets. Those marketed species includes well-known species as *Lactarius group deliciosus*, *Tricholoma terreum*, *Hygrophorus latitabundus*, *Cantarellus lutescens*, *Craterelleus cornucopioides* or *Hydnum repandum*.

Models for *P. halepensis* forest were applied to the *P. pinea* and *P. pinaster* forests, due to the similarity of ecological conditions for all three species in the Catalonian region. *P. uncinata* dominated forests, were excluded from the study due to the difficulty in applying current models to this species that occupies more extreme ecological conditions. The selected mixed linear models were able to predict (R^2 value an p-value) average annual values for total production of mushrooms, production of edible mushrooms, and production of marketable mushrooms, depending on forest growing stock variables, and three topographical variables (elevation, slope and aspect). Additionally, the models were able to correct for the interannual variability of the mushroom production depending on the precipitation data for each year.

The models used were as follow:

$$\ln(y_{ij}) = \beta_0 + \beta_1 \times \ln(G_{ij}) + \beta_2 \times \sqrt{G_{ij}} + \beta_3 \times \ln(Ele_i) + \beta_4 \times \ln(Slo_i + 1) \times \cos(Asp_i) + u_i + u_j + \varepsilon_{ij} \quad (1)$$

where y_{ij} is the mushroom production of plot i in year j (kg/ha/yr), G is stand basal area (m²/ha), *Asp* is aspect (rad), *Slo* is slope (%, i.e. 45 degrees is equal to 100%), *Ele* is elevation (m a.s.l.), u_i is random plot factor, u_j is random year factor, and ε_{ij} is residual. The random plot factor is further explained by the slope, dominant tree species of the stand, and whether the stand was naturally regenerated or planted; the random year factor is explained by the mean autumn rainfall of the region. All models (total, edible or marketable production of mushrooms) were based on the same explanatory variables, being the value of the coefficients (β_0, β_1, β_2, β_3 and β_4) that define the type of mushroom production to be predicted (see Bonet et al. 2010).

1.2.2 Generating unitary production at plot level across Catalonia

One requirement to predict mushroom production using the models of Bonet et al. (2010) is to have forest basal area data and tree species composition at stand level. The forest data used for this purpose were obtained from the 3rd Spanish National Forest Inventory (IFN3) (DGCN 2003). The IFN data consist of a systematic sample of permanent plots, distributed on a square grid of 1km, with a re-measurement interval of 10 years. The sampling design uses concentric circular plots with radius depending on the tree diameter at breast height (dbh). For Catalonia, the IFN3 took place during 2000 and 2001, and includes approximately 9,400 forest plots. From all IFN plots, only data from those dominated by pines were suitable to be used for predicting mushroom production (4044 plots with at least 80% of the basal area corresponding to pine trees). For those plots dominated by pine species the models from Bonet et al. (2010) were applied and mushroom production (kg/ha) predicted. If a forest plot was dominated by a mixture of pines (more than 80% of the basal area being pines but no single species reaching the threshold of 80% of the basal area), the model for the most abundant species was applied. The IFN data was sufficient to obtain average annual mushroom productions, but additional data on climate was required to estimate the random year factor and therefore capture the interannual variability of the mushroom production. For the climate data, records from the meteorological station of *Pinós del Solsonès*, UTM zone 31N (377232, 4628439), was used to assess the variability between 1995 and 2008. We selected this meteorological station because it is located approximately in the center of Catalonia, representing average weather conditions at regional level.

1.2.3 Generating the area of influence of the productive forest plots

Conversion of point-based data provided by the IFN plots into forest areas of similar characteristics is a necessary step to map mushroom production and calculate aggregated productions at the regional level. As the IFN is based on a regular square lattice, the simpler way to convert is to create a square tilling, where each square has 100 hectares of area and the IFN plots are located in the center of those squares to be considered as forest. Another possibility is the use of Voronoi tessellation (Boots 1986) to define areas of influence around each of the NFI plots. Voronoi/Thyessen polygons are defined in a way that the polygon boundaries are equidistant from neighboring points and each location within a polygon is closer to its contained point than to any other point. One characteristic of applying this methodology is that in areas where a complete square lattice of forest plots is set, Voronoi polygons will take the form of a regular square tilling, but areas where IFN plots are absent would be covered by polygons representing the influence of the nearest IFN plot. This characteristic has the advantage of inclusion in the forest/mushroom production mapping all forested areas, even if no IFN plots were located in the area. However, this method covers the whole surface of Catalonia with polygons, or areas of influence, thus greatly overestimating its forest area. To solve this problem, we clipped the Voronoi polygons with the Spanish forest map 1:50000, MFE 50 (BDN 2001), erasing any area not representing forest with a pine species as the main specie.

1.2.4 Calculating the total production of mushroom for Catalonia

As result of the previous steps, a map with forest areas dominated by pines was generated. By using the MFE50 to eliminate all non-desired zones from the Voronoi polygons a higher degree of reality in terms of better approximating the irregular edges of the forest was obtained. The areas in the map were given a value for the growing stock and topographical variables equal to the one of the nearest forest inventory plot, and its correspondent unitary value for mushroom production (total, edible and marketable mushrooms). In a final step the surface of the mushroom producing areas was calculated, and the regional production of mushrooms estimated.

1.2.5 Estimating the total value of mushroom production

Individual and total pine stand productivity was finally economically determined assigning an economic price to both edible and marketable yields. An estimated price of 2 and 4 €/ha were assigned to the edible and marketable productions respectively, based on the published data of Martínez de Aragón et al. (2011) who establishes a medium price around 3.5 €/ha of the commercial mushroom and by Aldea et al. (2012) who fixes a commercial price paid to the mushroom pickers between 3-4 €/ha.

2 Results

The average yield production of mushrooms in pine forests in Catalonia was estimated to be 45.65 kg/ha per year. However, it was observed that the estimated production varied drastically between the different pine forests, depending on the dominant pine specie (Table 1). For example, the average production of mushrooms, regardless of its dominant specie, in the case of *P. pinea* forest was found to be 0.95 kg/ha, whereas in the case of *P. sylvestris* forest reached 135.29 kg/ha. The variation in the production of mushrooms depending on its supporting forest and the dominant pine species comprising the forest was found to follow an altitudinal gradient, with the forests growing in Pyrenean mountains at higher altitude, and in moister places, tending to have higher mushroom productions (Figure 3). This altitudinal- and tree species-related trends maintained for all the species of mushrooms. The production of edible and marketable mushrooms was higher for *P. sylvestris* forest, with 89.68 and 44.88 kg/ha respectively, and lower for *P. pinea* with 0.59 kg/ha of edible mushrooms and 0.13 kg/ha of marketable mushrooms.

By calculating the areas of forest with similar characteristics, and consequently equal mushroom yields, it was possible to make predictions about the region's total, edible and marketable stock of mushrooms in the pine dominated forest. Our predictions estimate that the total production of mushrooms in pine forest, close to 24,500 tons per year, the edible mushrooms accounting for more than 16,300 tons and the marketable almost reaching 8,000 tons which means a total value of around 48 and 32 millions of € for the edible and marketable productions respectively. As expected, *P. sylvestris* forests were found to produce most of the mushrooms of Catalonia, due to the combination of area dominated by this species and mean yield (Table 2). When considering the results obtained for the regional production of mushrooms, the annual precipitation in Catalonia that varies both in amount and time with important interannual fluctuations in autumn rains should be taken into account. These results presented here are based on forest stand and the average climatic conditions of the period 1995-2008 (Figure 4). If the climate and essentially the autumn precipitations are taken into account, the total production of mushrooms could vary from almost no production for a dry year to over 60,000 tons for a rainy year (Figure 4).

Table 1 Annual average productions of mushrooms yield depending on its supporting forest type. TY = Total yield, EY = edible yield, MY = marketable yield; S.D.=Standard Deviation.

Dominant specie	Surface (ha)	TY (kg/ha)	S.D.	EY (kg/ha)	S.D.	MY (kg/ha)	S.D.
P. pinaster	4,215	2.08	8.17	1.29	5.40	0.31	0.98
P. nigra	72,826	10.27	20.53	7.33	16.28	1.45	2.29
P. halepensis	232,129	2.12	4.63	1.36	3.08	0.26	0.54
P. pinea	14,744	0.95	2.78	0.59	1.89	0.13	0.32
P. sylvestris	133,838	135.29	235.51	89.68	166.73	44.88	61.41
Mixed pines	6,050	14.08	38.15	9.51	25.35	2.29	7.99
Total	463,802	45.65	145.49	30.35	101.92	14.51	40.06

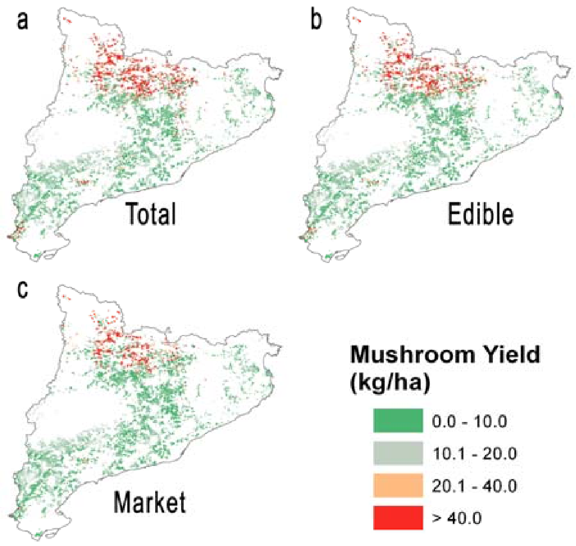

Figure 3 Total, edible and marketable mushroom production maps.

3 Discussion

Catalonia, with an approximate 60% of forest land, of which 40% is wooded land (those surface covered by tree species) represents a typical situation of the mountainous regions of the northern Mediterranean basin. The Pyrenees Mountains have historically been managed during centuries to ensure food production for the population, reaching the maximum of agricultural land expansion at the end of the nineteenth century (Ameztegui 2013). From the beginning of the twentieth century and particularly since the 1950´s a sharp depopulation process occurred with a rapid transformation of exploitation systems and socio-economic organization of landscape (Molina 2002), being intensively exploited the most fertile areas (valley bottoms) with the consequent abandonment of the less accessible or productive farmlands in sloping mountainous areas (Ameztegui 2013). The results of all these changes led to a progressive increase of woodland areas by colonization of abandoned lands (Lasanta et al. 2005). The National Forest Inventories indicate that the number of forest surface in Catalonia was doubled in the last forty years (MMA 2005).

Despite the increase of forest area during the last decades, only a minimum number of hectares are subjected to an active management (Rabascall 2011), which is limited to the timber management of few private lands where timber production is profitable or to fire prevention management supported by the government in private and public lands.

Consequently, forest policy is mainly limited to establish criteria to obtain subsidies to enhance forest management, and is highly dependent on the occurrence of large disturbances such as forest fire and lacks the long-term continuity required to implement forest management plans (Vayreda 2004). Planning forest management for achieving multiple objectives, directed at increasing the multifunctional nature of the forest, can be a means to making forest management profitable and stimulating the economics of mountainous areas. By sharing common operational costs but yielding different valuable products and services, the net revenue obtained from multifunctional forest management will result in a non-negative or even attractive investment as demonstrated by Palahí et al. (2009) who presented, from our knowledge, the first approach for a multifunctional silvicultural schedule to include both timber and mushroom productions.

In order to implement forest management strategies, they must be economically sustainable over long periods. Even if timber management does seldom fulfill such requirement, our forests have the capacity for providing multiple other products and services that should be taken into account (FAO 2012) and mushroom yields should be a profitable resource as is demonstrated in the

Table 2 Total, edible (including both marketable and non marketable) and marketable mushroom productions (Tons) and their associated value (1000 €) by forest type.

Dominant specie	Total yield (Tons)	Edible yield (Tons)	Value (1,000 €)	Marketable yield (Tons)	Value (1,000 €)
P. pinaster	9.2	5.8	14.4	1.4	5.6
P. nigra	1,072.8	769.5	1,830.4	145.7	582.8
P. halepensis	435.9	278.0	660.8	52.4	209.6
P. pinea	19.1	12.1	29.0	2.4	9.6
P. sylvestris	22,860.3	15,208.1	45,817.4	7,700.6	30,802.4
Mixed pines	105.1	75.2	178.0	13.8	55.2
Total	24,502.4	16,348.7	48,530.0	7,916.3	31,665.2

present work. The substantial mushroom productivity of the Catalonian forests, as estimated in this study, with a mean of 45 kg/ha and a maximum of 135 kg/ha of mushrooms in Scots pine forests supports this expectation.

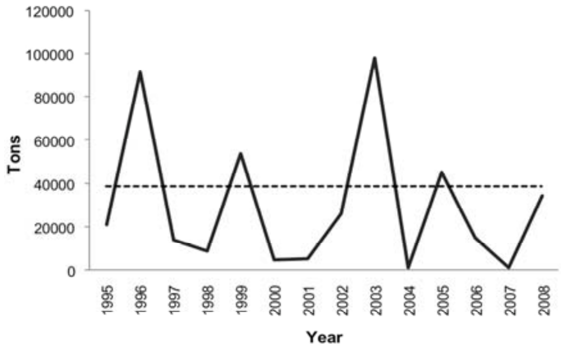

Figure 4 Variability of total yield of mushrooms in Catalonia depending on the annual climatic conditions. Dashed line represents the total mushroom yield dependent only on the forest structure.

Although many edible mushrooms have a well-defined value in the food markets, their collection has become a very popular recreational activity. In Catalonia scores of persons dedicate a significant part of their autumn to this activity (approx. 2 million people, 35% of the total population (CERES 2008)), some for commercial purposes and the vast majority as a healthy outdoor activity.

Mushroom picking has a clear beneficial effect on rural economies in the mountainous areas, directly through the earnings of local commercial pickers or indirectly through the influence that the recreational visitors have on the local commerce (shops, restaurants or hotels) as is demonstrated by Martínez de Aragón et al. (2011) who reported a total surplus of 586,000 € generated by the mushroom activity in an autumn season in the county of Solsonès (Pre-Pyrenees Mountains, Catalonia) using the travel cost method. Martínez-Peña (2007) who reported that the economic activities based on mushroom potential mushroom collecting activities and mycology-based tourism may involve more than 50% of the rural population in *Castilla y León* region (Spain), estimating that the regional economy related to the harvesting of wild edible mushroom could reach 65 million of euro in some favorable years. Furthermore, the regional government of this region, with the support of the research community, forest owners and rural associations, has promoted a program aimed at establishing a global plan in order to manage collectively, regulate and commercialize these productions (www.myasrc.es). This was initiated as a pilot experience in some forests in 2003 and rapidly expanded to other public forests and to other provinces in the *Castilla y León* region. Such a program represents an example of the great interest that the mushroom sector arouses among numerous stakeholders today.

The present study is the first approach to estimating mushroom productivity and corresponding economic value at the regional level based on mushroom plot surveillance, being our results in line with those of Martínez-Peña (2007). The potentiality for mushroom production found on the study, highlights the relative importance of this type of non-wood resources on a Catalan forest sector in which wood production only accounted for approximately 11 million Euros per year during the past decade (Terradas 2004). On a deprived forest sector, that accounts for only a 4.28% of the gross income of a region covered by forest and shrublands on a 61% of its territory, it is clear the importance of put on value and manage the forest considering the opportunities that non-wood forest products offer, together with the growing relevance of forest biomass as a renewable energy source. The mycological maps and the figures of the total sporocarp yields obtained in the present work open the door to the establishment of a forest policy that also considers the mushroom productivity as a means to increase the economic activity of rural communities in forested mountainous areas.

Considering that mushroom production greatly depends on the state of the forest (Bonet et al. 2008, 2010), and its yield can be enhanced or diminished through forest management, as is demonstrated by Bonet et al. (2012) who shows an increase of *Lactarius* group *deliciosus* yields after a forest thinning, the public effort, through the policy of subsidies, should be concentrated on the most suitable areas. These areas can be identified from the mycological maps obtained. Furthermore, a study to evaluate the possibility to establish taxes or other policy instruments which regulate the revenue derived from the mushroom production and related activities is a useful step in long-term management of thee mushroom resources.

The weekly surveying of permanent plots during the autumn season, with the identification and weights of all the epigeous mushrooms that appear in these plots (Bonet et al. 2004), allows us to estimate the amount of total, edible and marketable mushroom yields, showing the importance of edible productions and the future potential of those edible fungi which are not yet sold in the markets. Nevertheless, in the present study some limitations associated with the methodology should be discussed. The first limitation is that the models have been developed for some tree species but not all the species. By extrapolating the *P. halepensis* yield models to *P. pinea* and *P. pinaster* forests, species due to their similar ecological conditions, we may be underestimating their productivity. However, the potential error caused by using a model for *P. halepensis* on the *P. pinea* and *P. pinaster* forests can be assumed to by relatively small when adding up their production to the overall regional production, as those two species represent merely a 3% of the pine forest. The second limitation is due to the fact that the range of stand conditions in the yield based plots from which the models were constructed (basal area, elevation, slope), do not cover all the conditions that can be found on the Catalan forests, in terms of stand structure, geography or climate. Therefore, it can be expected that by applying the models on forest data that are out of the range of the parameters that were used to generate the models, potential errors are to be expected. This limitation, as the previous one, can hardly be solved unless new sampling plots are established covering a wider range of conditions and species, and new models developed. Because of this limitation, we choose to not include *P. uncinata* on the present study, as it is the regional pine species whose forest stand characteristics differ the most from the modeling data range. A third limitation is related to the extrapolation of data from inventory plots. Although there are many plots and systematically located (full cover), extrapolation may introduce some errors. In order to estimate regional scale production and develop mushroom maps that represent potential production it is necessary to run the models knowing that there is some inherent error. Finally, the use of a single meteorological station to capture interannual variability of mushroom production can be considered an over simplification that does not reflect the true variability of climatic conditions that can be found at the regional scale. However, an estimation of the importance of mushroom production at a regional scale, or the process of showing, though maps, which areas have a higher potential for producing mushrooms, can be illustrated through the mean annual value, as presented in the study. The interannual variability of the mushroom production was notably included to illustrate the relatively high uncertainty that can be observed on mushroom yields, and the need of consider the potential effect of climate change if long term strategic planning is to be developed.

This demonstrates the need for further studies to consider the establishment of models with more forest species and more stand conditions. New models will allow for greater accuracy and efficiency in obtaining outcomes to enter into the analysis of strategic forest planning at the regional scale. This will facilitate the use of different management scenarios with the consequent evolution of the forest, and the inclusion of the effects of multiple variables, particularly the weather factor associated with the climate change. New studies will help both forest managers and policy makers to highlight the importance of the mushroom productions, providing real opportunities to create new profitable activities in forested mountainous areas.

Acknowledgments

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