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Review

Climatic and Socioeconomic Aspects of Mushrooms: The Case of Spain

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Abstract: Fungi are some of the most diverse organisms on earth and since prehistoric times have played an important role in human society. In recent years they have become a strategic asset not only in the conservation and management of ecosystems but also as a resource for halting the exodus from rural areas in peripheral Mediterranean regions, such as inland eastern Spain. In view of this important ecological and socioeconomic role, in this paper we present a geographical analysis of edible fungi, paying particular attention to the Spanish case. To this end we carried out a bibliographic review of the climatic factors affecting the fruiting of these fungi and the socioeconomic aspects of their commercial exploitation. We also performed an online search for mycotourism-related activities and explored the statistical data on the cultivation of edible mushrooms and its economic impact. Our main findings include a synthesis of the international research on the effects of climatic variability on the natural production of macrofungi, and an assessment of the economic viability and the social importance of mushrooms in Spain, in particular in relation to the current and future potential of mushroom cultivation and the multifunctional management and use of forests.

Keywords: edible mushroom cultivation; environmental factors; Spain; sustainable rural development

1. Introduction

Fungi are some of the most diverse organisms on Earth [1]. They have played and continue to play a crucial role in the planet's ecology [2]. This role can briefly be summarized in three main aspects: (a) as essential elements in the colonization of the Earth by terrestrial vegetation [3]; (b) as decomposers [4–8] and bioremediation agents (mycoremediation) [9–12]; and (c) due to the basic symbiotic relationship established between fungi and their host species through the mycorrhizas [13]. This relationship can be established with most plants [14] and protects them from disease [15–17], helps them in situations of hydric stress [18–20] and increases the productivity of forest species [21]. These important contributions have enabled fungi to become a strategic component in the conservation and management of ecosystems, such as those in the Mediterranean region [22].

Man's relationship with fungi dates back to ancient times and in many cultures they acted as a "bridge" between the earthly and the divine [23]. They are also a source of food in themselves [24,25], and have enabled the production of such essential foodstuffs and medicines as bread, cheese and penicillin [26]. In recent decades their commercial use has also become increasingly important. In peripheral Mediterranean regions such as mountainous rural areas, their commercial exploitation can yield significant economic returns [21,27–29]. In fact, their direct harvesting together with mushroom-related activities in the tourism and restaurant sector can provide more income than that traditionally obtained from forests as a source of timber and wood pulp [28]. When used in this way, fungi have helped maintain rural population levels and have improved general social welfare in declining areas [30].

To this end, in this paper we present both a review of the bibliography on climatic and socio-economic aspects of mycology and the results of an online search for mushroom-related tourism activities. We also analysed the statistical data in order to find out more about the bidirectional relationship between macrofungi, society and the environment. Our main objectives were: (a) to assess how climatic variability affects their fruiting and phenology; (b) to analyse the current trends and situation of the cultivation and natural production of mushrooms and truffles at a worldwide level and in Spain; and (c), to describe the socioeconomic impact and future potential associated with the picking of wild mushrooms and their cultivation in forests. In this study we focused particularly on the geographical distribution of mushroom production and of mushroom-related tourism products in Spain.

2. Materials and Methods

In this paper we carried out an exhaustive bibliographical review of: (a) the environmental factors affecting the fruiting of wild macrofungi, especially those related with the climate; and (b) the multifunctional use of forest spaces, focusing particularly on the commercial exploitation of wild edible fungi, mycological or mushroom-related tourism and fungi as a part of silviculture (Figure 1).

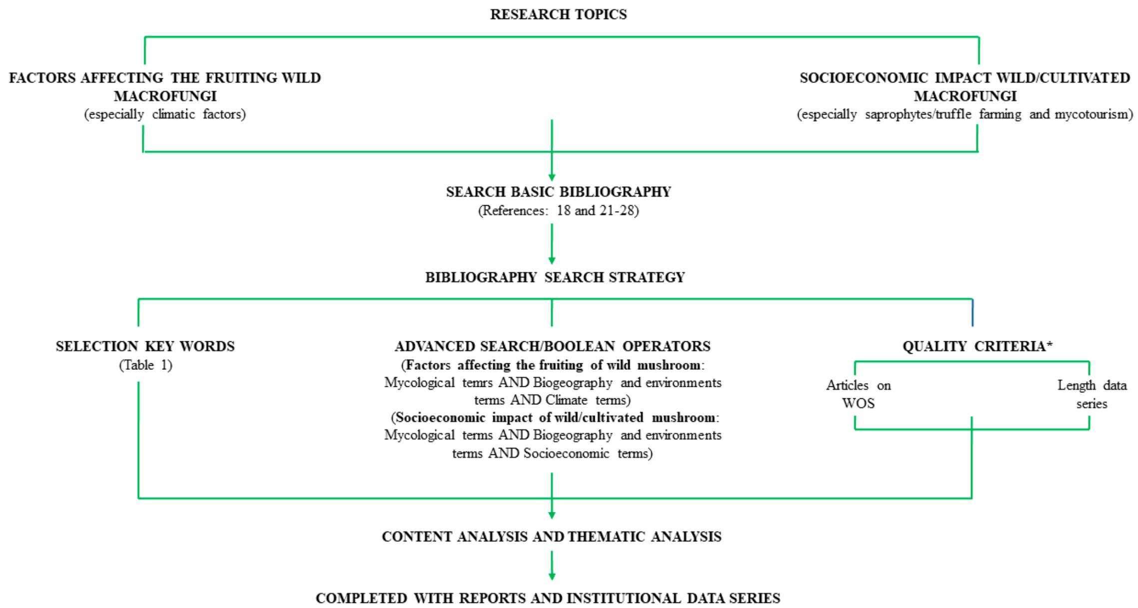


Figure 1. Procedure followed in this research. *In case of various publications.

We began by consulting Google Scholar to find articles on the various subjects on which we were focusing [31]. These included: (a) the influence of climate on the wild fruiting of macrofungi [32]; (b) the consumption, price and production of hypogeous fungi [33–35]; (c) the commercial exploitation of wild fungi in forest areas [36]; and (d) mycological tourism [28,37–39]. In these articles we found other references of interest, which in turn cited other important research on the questions being studied here, so providing a positive feedback loop within the bibliographical analysis.

With all this information, we selected various search terms relating to mycology, biogeography, climate, socioeconomics and tourism (Table 1). We searched for these terms in various bibliographic databases. For research about Spain we consulted the Spanish National Research Council (CSIC) database [40] and for international research we consulted the Web of Science (SCI) [41]. The search criteria were applied with Boolean operators.

Table 1. Keywords used in our searches on bibliographic databases.

Mycological Terms	**Sporocarp; Fungi; Macrofungi; Macromycetes; Mycelium; Mycoflora; Mycorrhizas; Mushrooms; Truffle; Tuber**
Biogeography and Environment Terms	Thinning of forest; biogeography; time changes (in fruiting patterns); forest cover; chorology; fruiting bodies; diversity; age of the forest; endemicity; seasonality; environmental factors; phenology; fruiting patterns; habitats; hygrophilous; distribution models; niche; pending; production; sporocarps; thermophilic; geographical variation; xerophyte
Climate Terms	Global warming; climate; climate change; weather; evapotranspiration; precipitation; drought; temperature; meteorological variables; Hydric Balance
Socioeconomic Terms	Economic profit; economic contribution; development; rural development; employment; gastronomy; forest management; socioeconomic impact; income; mycotourism; multifunctionality of forests; price; non-wood forest products; mushroom picking; truffle picking; edible mushrooms; silviculture; tourism; mycological tourism; economic value; economic variables; sales

Source: Created during this research.

We have also consulted various reports by the Food and Agriculture Organization of the United Nations (FAO) [42] and the Spanish National Statistics Institute [43] for information on the consumption and cultivation of mushrooms and truffles and the profitability of these crops. The data we obtained was analysed for possible trends and its coefficient of determination was calculated, from exponential trend line for global data and from potential trend line for Spain data. The data on the profitability of agricultural crops in Spain for the period 2010–2014 was obtained from the Ministry of Agriculture, Fishing, Food and the Environment (hereinafter MAGRAMA).

In order to quantify and locate the leisure and tourism activities related to mycology we consulted various online information sources to find out more about the mycological interpretation centres, mycological parks and mycological fairs held during the 2016–2017 season in Spain. We applied the Hjalager classification system (horizontal, vertical and diagonal developments) for identifying the processes involved in the creation of tourism products [44] and extrapolated these considerations to mycological tourism.

The information was classified into the following themes or subjects: (a) environmental factors affecting the natural distribution of macrofungi; (b) the climate as a predictor of the natural fruiting of macrofungi carpophores; (c) phenology, phenological patterns and recent trends in the natural production of macrofungi, a symptom of climate change? (d) cultivation of edible mushrooms (especially saprophytes) in artificial environments and their consumption; (e) truffle farming and future potential for peripheral rural areas; (f) multifunctional management of the mycological landscape; (g) environmental income from forest resources, mycological tourism and mushroom-related silviculture.

3. Results and Discussion

3.1. Climate as a Predictor of the Natural Fruiting of Macrofungi Carpophores

In our analysis of the influence of atmospheric conditions on the fruiting of fungi we initially identified two large climatic groups, based on the available supply of water. In climates in which there are no water limitations, (e.g., oceanic climates in the temperate zone), the relationship between climate and the fruiting of fungi is likely to be more influenced by bioecological factors than by physical ones (such as climate). In these climates, droughts and heatwaves are normally less severe and shorter than in climates with limited water supply and therefore have less impact on fruiting [45]. In climates with a dry season or limited water levels, the climatic influence over the interannual variation in the production of fruiting bodies should be more evident. This has been demonstrated in the Mediterranean region [6,21,46–50].

We will now consider the effects of precipitation levels and temperatures separately. In the case of epigeous fungi, an increase in fruiting has normally been observed if there have been generous amounts of rainfall in the period running up to the fruiting season [6,47,48]. In this case it is clear that the moisture in the soil is the main conditioning factor in the appearance of carpophores [32]. It is also important to emphasize that the relationship between the fruiting of fungi and climate conditions is not always immediate [51–53]. As regards temperatures, if these are higher than usual, this can produce hydric stress in the fungi, so leading to a fall in production: this is what happens for example with *Tuber melanosporum* (black truffles) in the Mediterranean area [32,45]. However, if high temperatures do not cause hydric stress, they can extend the fruiting period and increase production [54].

Some researchers have divided the fungi into different functional groups (saprophyte and mycorrhizal species). In these cases, the results, although not identical, have displayed certain similarities [6,45]. As regards spatial distribution patterns, it would seem that a lack of water seems to have a stronger influence on the saprophyte species [1], given that they develop just below the ground surface and are therefore more vulnerable to drought conditions [55].

Table 2 offers a synthesis of the most representative results obtained at an international level. The different climatic areas and variables are specified. The data are offered at a general level without distinguishing between species of fungi. Only the papers that have analysed long data series are included. The research on epigeous species appears first, followed by the work on hypogeous fungi.

Table 2. Most representative studies of climatic predictors of natural production of macrofungi sporocarps.

Geographical Data	Mycological Data	Main Results	References
SW Yukon, Canada Climate: Dfc	EF (annual), 15 years ECM and SAP	Biomass r May P (tyear-1) = +0.75 r June P (to) = +0.68	[52]
Chanéaz, Switzerland Climate: Cfb/Dfb	EF (annual), 36 years ECM	Carpophores (number) r annual T (to) = +0.92 (12-annual moving average)	[56]
Chanéaz, Switzerland Climate: Cfb/Dfb	EF (annual), 36 years ECM and SAP	Carpophores (number) r April and August T (to) = +0.72 r $\sum$ P (to) = +0.5	[45]
Higashiyama, Japan Climate: Cfa	EF (annual), 30 years ECM and SAP	Carpophores (number) r monthly T (to) $\approx$+0.5 r $\sum$ P (to) $\approx$+0.5	[57]
Soria, Spain Climate: Csb (2)	EF (autumn), 15 years ECM and SAP	Biomass r $\sum$ P (t$\geq$10 days) = +0.64	[6]
Pyrenees, Spain Climate: Cfb/Csb	EF (autumn), 13 years ECM and SAP	Biomass r $\sum$ August–November P (to) = +0.86	[47]
Mediterranean, Europe Climate: Cfa/b-Csa/b	HF (winter), 37 years ECM *Tuber melanosporum*	Biomass r $\sum$ July-August P (tyear-1) = +0.6 r means July–August T (tyear-1) = −0.57	[49]
South of France Climate: Csa (2)	HF (winter), 24 years ECM Tuber melanosporum Tuber brumale (5%)	Sales from two main markets r $\sum$ May–August HB (tyear-1) = +0.61 and + 0.68 (depending on the market)	[50]

Legend: Climate Köppen Climate Classification [58]. The numbers in brackets in Column 1 are the number of dry months; Mycological data (EF = Epigeous Fungi; HF = Hypogeous Fungi; ECM = Ectomycorrhizal Fungi; SAP = Saprophyte Fungi); Main findings (r = correlation coefficient; to = current year; t $\geq$ 10 = after at least 10 days; tyear-1 = previous year); Climate variables (P = Precipitation; T = Temperature; HB = Hydric Balance). In order to help readers interpret the data shown in Tables 2 and 3, we will now describe the study in Yukon (Canada) in more detail as an example. According to the Köppen classification, this region has a Dfc climate (snowy climate, very humid, cool summers and cold winters). Researchers tracked annual biomass production of epigeous fungi (both saprophyte and ectomycorrhizal) against different climatic variables over a period of 15 years. Their most important results showed a relationship between biomass production and monthly precipitation in May (previous year) (r = +0.75) and between biomass production and precipitation in June (current year) (r = +0.68). Source: Created during this research.

3.2. Phenology, Phenological Patterns and recent Trends in the Natural Production of Mushrooms, A Symptom of Climate Change?

Normally the fruiting of fungi follows a seasonal pattern and is affected by climatic factors, in particular temperature and rainfall [51]. In temperate areas in the northern hemisphere most of the fleshy mushrooms fruit in autumn, while a few species, above all the ascomycota group, have adapted their fruiting to the spring [32]. In functional terms, in Australia, Norway, United Kingdom and Switzerland it has been observed that the ectomycorrhizal fungi tend to have a shorter fruiting period than the saprophytes [32]. By contrast, one of the world's finest delicacies, the black truffle (*Tuber melanosporum*) fruits in the winter from November to February [59]. In general, there are few references in the literature about the phenology of the mycelium. Nonetheless, the production of mycelium and the fruiting of the carpophores seem to occur at different times [60].

The phenological changes observed in the biome as a result of climate change are also being observed in fungi [2,32,45,46,49,53,57,61–63]. The evolution of phenological patterns and the tendencies observed in production vary according to the climatic context. A lengthening of the fungi fruiting season has been detected in temperate areas without summer droughts, such as Austria, the United Kingdom and Switzerland [2,61]. In some cases, for example in Switzerland, this leads to an increase in total annual production [45]. However, in situations in which there are limited supplies of water, the opposite has occurred. This is what has happened, for example, in such representative species as Matsutake (*Tricholoma matsutake*) in Asia [46] and *Tuber melanosporum* in Europe [49,61]. In view of the worldwide importance of *Tuber melanosporum*, it is interesting to note that given the climatic factors that influence its natural production [32,64], it is likely that global warming will reduce harvests in its current niche areas (as indeed is already happening), and that the most suitable areas will shift northwards to the calcareous regions to the north of the Alpine arc [47]. Table 3 offers a synthesis of the results obtained at an international level on the phenological changes for various different geographical areas.

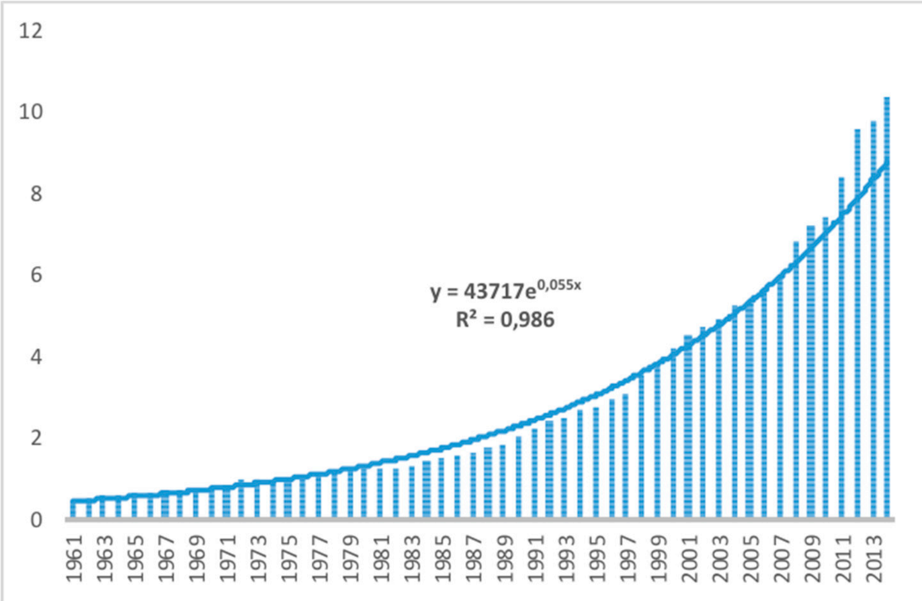
3.3. Cultivation and Consumption of Fungi

We should begin by offering a general global overview of fungi cultivation (mainly indoor cultivation of saprophyte species) at a worldwide level. To this end we used production data for mushrooms and truffles (1961–2014) and their associated gross economic worth (1961–2014) for the whole world (aggregated data), according to statistics from the FAO [42]. The most noticeable trend is the continuous, very rapid increase over time in both variables (production: trend 18 million tonnes/10 years, R^2 = 0.986 exponential trend line; gross worth: trend 36.4 thousand million constant US dollars/10 years, R^2 = 0.9797 exponential trend line), especially since 1990, as shown in the figures regarding global production of mushrooms and truffles and their gross value (Figure 2a,b).

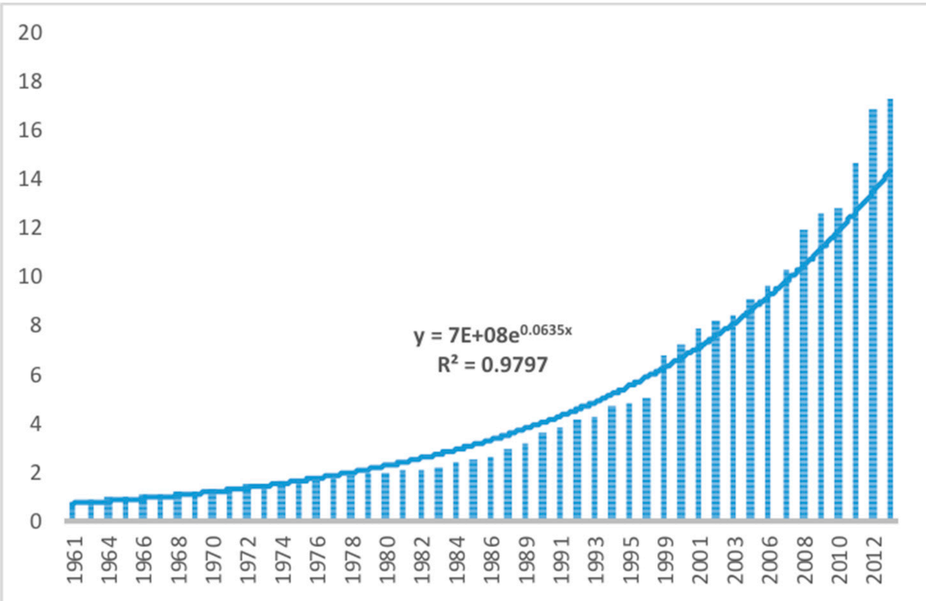
Table 3. Most representative studies of phenological patterns and analysis of trends in the production of macrofungi sporocarps.

Geographical Data	Mycological Data	Most Important Results	References
Norway and the United Kingdom Climate: ET, Df, Cfb	EF (spring), 48 years ECM and SAP (mainly)	Carpophores (number) 1. Phenological changes:tart of season has moved forward (3.8 days/decade)	[53]
Norway, the United Kingdom, Austria and Switzerland Climate: ET, Df, Cfb	EF (autumn), 38 years ECM and SAP	Carpophores (number) 1. Phenological changes: Lengthening of the season (start delayed and finish delayed) with differences between species and countries	[2]
Michigan, USA Climate: Dfa/b	EF (annual), 101 years ECM and SAP	Carpophores (number) 1. Phenological changes: Start delayed (0.18 days/decade) with differences between functional groups and host types (deciduous vs evergreen) 2. Production trends (=)	[65]
Chanéaz, Switzerland Climate: Cfb/Dfb	EF (annual), 36 years ECM and SAP	Carpophores (number) 1.Phenology: peak of production (September-October) 2. Phenological changes: Start delayed (13 days from 1975 to 2006) with differences between functional groups and host types (deciduous vs evergreen) 3. Positive production trends in both ECM and SAP	[45]
Chanéaz, Switzerland Climate: Cfb/Dfb	EF (annual), 36 years ECM	Carpophores (number) 1. Phenology: peak of production (September-October) 2. Phenological changes: delayed peak production (1975-1990/1991-2006: 10 days) and lengthening of season 3. Positive production trends(1975-1990/1991-2006: number of carpophores per week from 42 to 88)	[57]
Salisbury, United Kingdom Climate: Cfb	EF (autumn), 56 years ECM and SAP	Carpophores (number) 1. Phenological changes: lengthening of season: from 33.2 ±1.6 days in 1950 to 74.8 ± 7.6 days in 2005 (start brought forward and end delayed)	[66,67]
Higashiyama, Japan Climate: Cfa	EF (annual), 30 years ECM and SAP	Carpophores (number) 1. Phenology: ECM unimodal pattern: peak production (July); small decomposers bimodal pattern: production peaks (early summer and early autumn) 2. Positive production trends only wood decomposer fungi (due to aging of the forest)	[58]
Soria, Spain Climate: Csb (2)	EF (autumn), 15 years ECM and SAP	Carpophores (number) and Biomass 1. Phenology: start 40.4 ± 0.6 weeks, end 47.5 ± 0.5 weeks), duration (7.1 ± 0.7 weeks)	[6]

Legend: Climate (Köppen climate classification. In brackets in Column 1 the number of dry months); Mycological data (EF = Epigeous Fungi; HF = Hypogeous Fungi; ECM = Ectomycorrhizal Fungi; SAP = Saprophyte Fungi). Source: Created during this research.



(**a**)



(**b**)

Figure 2. (**a**) Global production of mushrooms and truffles in millions of tons, (**b**) Global production of mushrooms and truffles in gross value (constant values 2004–2006 in US dollars). Source: Food and Agriculture Organization of the United Nations (FAO) [42]. Created during this research.

China is the world's largest producer. In 2014, according to the same source and type of data, this country produced 74% of world production. Almost all (about 95%) of Chinese production was for domestic consumption [68].

Europe also plays an important role in the production of edible fungi and truffles. According to data from the FAO, apart from China, in 2014 the main producers were: Italy with over 600,000 tonnes; the United States with over 432,000 tonnes; the Netherlands with about 310,000 tonnes; and Spain with about 150,000 tonnes, slightly ahead of France [42].

According to data from the FAO (1964–2014), production in Spain has also increased fast (trend 19,600 tonnes/10 years, R^2 = 0.9023 potential trend line), especially since the mid-1970s.

The exponential growth of about 45,000 tonnes observed between 1999 and 2002 is especially noteworthy, as it appears in the figure about production of mushrooms and truffles in millions of tons in Spain (Figure 3). In addition, after a period of stagnation between 2006–2010, growth began again in 2010 and continued until 2012, after which production stabilized.

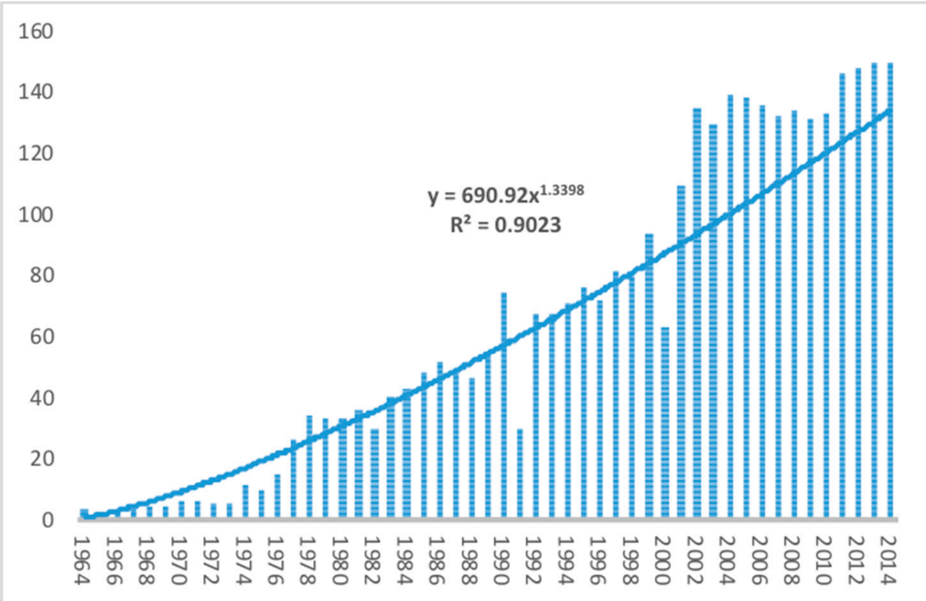


Figure 3. Production of mushrooms and truffles in millions of tons in Spain. Source: FAO [42]. Created during this research.

At a regional level in Spain, according to figures from MAGRAMA [43], the autonomous communities of La Rioja and Castilla-La Mancha together total 95% of national production, with 50% and 45%, respectively. Mushroom-growing in Castilla-La Mancha was concentrated in two provinces: Cuenca and Albacete, with 30% and 15% of total national production, respectively.

As regards the species produced worldwide, according to a report from 2015 (http://www.marketsandmarkets.com/Market-Reports/mushroom-market-733.html), although there are about 2300 edible fungi, only about 200 of these are cultivated. The most widely produced and consumed fungi in the world are white mushrooms (in particular *Agaricus bisporus*), shiitakes (*Lentinula edodes*) and other fungi from the *Pleurotus* genus. According to the same report, these species together made up about 76% of the fungi sold in 2013.

In Spain the most popular types are *Agaricus bisporus* and to a lesser extent, species from the *Pleurotus* genus. Together they make up about 70% of total consumption [69]. According to data from the MAGRAMA, both production and consumption of fresh mushrooms rose steadily between 2004 and 2013, although per capita consumption in Spain remains below the international average (1.8 kg compared to 3 kg/inhabitant/year worldwide) [70]. There is therefore considerable margin for increasing consumption of saprophyte mushrooms in Spain, which together with apparent growing interest in the consumption of species such as shiitake and different varieties of the king oyster mushroom (*Pleurotus eryngii*) could provide a business opportunity for rural areas.

3.4. Truffle-Farming and Future Potential for Peripheral Rural Areas

In addition to the cultivation of saprophyte species, there is also growing interest in truffle farming [71]. In Spain this is a much more recent innovation and has appeared as part of a strong commitment to rural development. Truffles belong to the Tuber genus of fungi of which there are about 40 species. Four of these have great commercial potential [35]: (a) *Tuber brumale*, or winter truffle; (b) *Tuber aestivum* or summer truffle, also known as *Tuber uncinatum*; (c) *Tuber magnatum* or white truffle, the most expensive truffle in the world, although its cultivation has yet to be mastered; and (d), *Tuber melanosporum* commonly known as the black truffle or Perigord truffle. Of these, the black truffle is the one that has sparked the greatest interest worldwide in economic, social and environmental terms.

The production of black truffle reached a peak in France in 1892 when a total of 2000 tonnes were produced [34]. By contrast, total production today is only around 60 to 70 tonnes a year (when it is estimated that demand could reach 1000 tonnes/ year). The biggest producers of black truffle in the world are France, Spain, Italy and Australia with 31.3, 15.9, 11 and 4.5 tonnes, respectively [34].

From its aforementioned peak in 1892 the production of *Tuber melanosporum* fell into sharp decline until the early 1970s when techniques were developed for its inoculation in various different hosts [34]. This enabled the cultivation of *Tuber melanosporum* around the world. The area given over to truffle-farming is currently increasing by around 2200 hectares a year in the main production centres (Spain, France and Italy with 1000 ha/year, 800 ha/year and 400 ha/year, respectively) [35]. These authors estimated that production would continue increasing by about 5.6% a year until 2020 [35].

The data above show that over the last four decades the cultivation of forest species (such as *Quercus ilex*) for the production of black truffles is becoming an economic, social and environmental alternative for rural areas in decline in the Mediterranean basin. Various towns and villages in the Sistema Ibérico region of Spain deserve a mention in this sense in that they have seized upon black truffle farming as a means of combating the problems posed by a shrinking and ageing rural population [72]. It is worth noting that the turnover associated with the annual production of black truffles is around 20 million euros in France, 18 million in Italy in 1999 and 4 million in Australia in 2012 [34], and that producers of black truffles in Europe are paid around 150–800 euros/kg for their produce [34]. The price in retail outlets in Paris or London has been known to reach as high as 2000–4000 euros/kg [34].

As regards the truffle market in Spain, the production levels for the different species and the prices paid to the producer/collector have been estimated as follows [35]: (a) black truffle, with an annual production of 8–40 tonnes and a price of 250–850 euros/kg; (b) summer truffle, an annual production of 42 tonnes/year and a price of 50–150 euros/kg; (c) brumale truffle (*Tuber brumale*), with a production of 1 tonne per year and a price of 100 euros/kg.

In Spain the main production areas for black truffles and summer truffles tend to have limestone soils, which are generally of poor quality for agriculture, which means that truffle farming, without taking into account the associated subsidies, can produce incomes up to three times as high as traditional crops [35]. Indeed, in Spain, France and Italy, the annual return per hectare on the cultivation of black truffles ranges between 19,424 euros and 66,972 euros (prices vary greatly in line with supply and demand) with an initial period of about 10 years to recover the investment and start making profits [35]. A comparative analysis of the return from truffle farming and more conventional crops is shown in Table 4.

The most important truffle-farming area in Spain is the Gúdar-Javalambre area, in the south of the province of Teruel, which has a small population of about 8600 people. In the 2013–2014 season it produced about 36 tonnes of black truffles out of a total Spanish production of about 40 tonnes. This figure is only slightly below total French production of between 40 and 50 tonnes [72]. The Gúdar-Javalambre area, which had a rapidly declining population due to the difficulties affecting traditional agriculture, has transformed its landscape over the last four decades with the plantation of 6500 hectares of black truffles [72]. Together with other new opportunities, such as rural and nature-related tourism, this has enabled them to stem the tide of rural exodus such that the population has remained stable since the 1990s, according to data from the Spanish National Statistics Institute (NE).

An idea of just how important truffle farming is in Spain and its geographical distribution can be obtained via an online search of the nurseries selling host trees that have been mycorrhized with *Tuber melanosporum*. We counted a total of 24 nurseries, nine of which were in the Aragón Region. These are centred above all in the Sistema Ibérico mountain range and in particular in the town of Sarrión in the Gúdar-Javalambre area, which has six nurseries This would suggest that the presence of these nurseries is related to their proximity to black truffle cultivation areas (Figure 4).

Table 4. Approximate average return (euros/ha/year) on other crops in Spain compared with truffle farming.

Type		Rain-Fed	Irrigated	Source
Herbaceous crops	Corn		2340	[73–76]
	barley	510	781	
	wheat	589	948	
	sunflowers	323		
	dried peas	267		
Vegetables	peppers (greenhouse)		54,723	[77–82]
	watermelons		10,408	
	tomatoes (greenhouse)		53,136	
	melons		6441	
Fruit	oranges		4384	[83–88]
	peaches		7623	
	olives (Mill)	905	2040	
	plums		9138	
	nectarines		9327	
	almonds		699	
Truffle farming	*Tuber melanosporum*		5400	
			19,424–66,972	[35]
			12,000	Production [89] and prices [35]
	Terfezia claveryi		1028	Production* [90] and price of 5 euros/kg

* The production of *Terfezia claveryi* varies a great deal from one year to the next. Source: Created during this research.

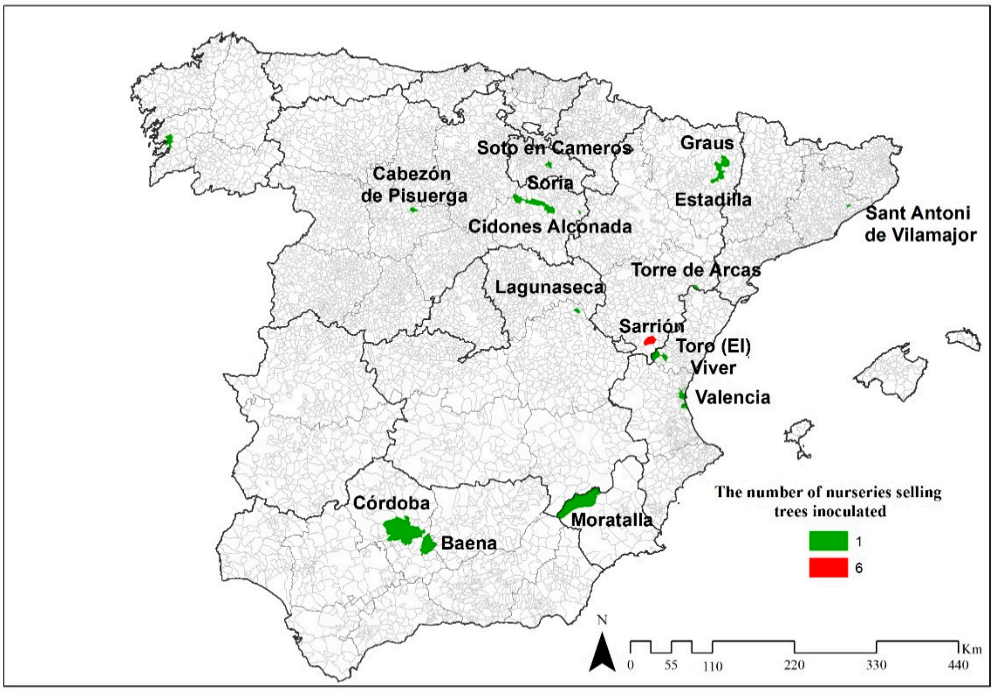


Figure 4. Distribution of nurseries selling trees inoculated with *Tuber melanosporum* in Spain in 2017. Source: Created during this research.

Increasing interest is also being shown in the cultivation of *Terfeziaceae*, or desert truffles. Although these hypogeous fungi are not as highly prized as black truffles, they still fetch an attractive price. They grow in arid, semi-arid and dry atmospheres all over the world, between the tropical and temperate latitudes. In Spain consumption of these fungi has aroused most interest in Extremadura and to a lesser extent in Murcia, Andalusia, Aragon and the Canaries [33].

The interest in *Terfeziaceae* goes beyond their culinary or gastronomic qualities [33]. They also have a high nutritional value and are of economic and ecological importance in that they can be used as a complementary crop for introducing sustainable forms of agriculture in semi-arid and arid rural areas. In Spain the return on *Terfeziaceae* farming is often greater than that from other traditional irrigated crops (Table 4). Since the first plantation of *Terfeziaceae* in the world in Murcia in 1999, there has been growing demand for this crop (91) and there are now over twenty such plantations in Spain [91]. Experimental results are also being obtained in Tunisia, Israel and Argentina [92].

3.5. Multifunctional Management of the Mycological Landscape: Environmental Return from Wild Resources, Mycological Tourism and Mushroom-Related Silviculture

Forest resources are associated with a wide range of products and benefits. In Spain the income from these products in 2011 was over 992 million euros (Table 5). The main source of income was timber with 72.7% (Table 5), although various other products also made important contributions. These included mushrooms and truffles, which together made up 11% of the income from forest resources. Apart from their economic contribution, it is important to highlight the ecological, social and recreational role they play in rural areas [93].

Table 5. Estimated economic value of the consumptive use of goods from forested areas of Spain (2011).

Product	Economic Value in Thousands of Euros	% of Total Economic Value
Logging	721,416 (Value in the loading bay in 2009)	72.7
Firewood	23,775 (Value in 2009)	2.4
Cork	51,242	5.7
Resin	4157	0.4
Esparto	2	0.0
Chestnuts	1200	0.1
Truffles	1293	0.1
Other fungi	108,350	10.9
Other fruit, plants and products	7443	0.8
Hunting and fishing	73,228.21	7.4
Total	992,106	100

Source: [94] and created during this research.

When it comes to assessing the commercial value of wild fungi, it is important to bear in mind that only certain species of wild edible fungi can be marketed fresh. These species are regulated and specified by Royal Decree 30/2009 of 16th January [95], which established the sanitary conditions for the sale of mushrooms for human consumption. To briefly summarize, the most representative saleable species (and therefore those that can be used for business and tourism-related purposes) are: (a) *Amanita ponderosa* (found in Mediterranean grasslands and Mediterranean scrublands with *Cistus* sp.); (b) *Boletus edulis* and *B. aereus* (in forests and grasslands with Mediterranean leafy trees, Atlantic forests of leafy trees, Euro-Siberian pine forests and Mediterranean scrublands of *Cistus* sp.); (c) *Cantharellus cibarius* and the *Craterellus* group (in forests with Mediterranean leafy trees, Atlantic forests of leafy trees, Mediterranean pine trees and Euro-Siberian pine forests); (d) the *Lactarius deliciosus* group (Mediterranean and Euro-Siberian pine forests); and (e), *Tuber melanosporum* (open forests of Mediterranean leafy trees such as *Quercus ilex*) (Source: this research, from observations in the field in different environments in Andalusia from 2012–2017, and the following bibliographical references: [95–100]).

One of the most interesting insights into the social and economic importance of mushroom picking in Spain was the study conducted in Andalusia [36]. About 6.3% of the population of Andalusia enjoyed picking mushrooms [36], as compared to 35% in Catalonia [101] and an estimated 54% of the rural population of Castilla León [102]. The importance of mushroom-picking is evident if we compare these results with those obtained (for Spain as a whole) for other activities performed in "natural" spaces: 4.4% of the population go skiing; 2.9% like fishing; and 2.4% go hunting [103].

For the specific case of Andalusia in 2010 the basic data for the economic valuation of mushroom picking indicate [36]: (a) that the total annual income obtained by pickers comes to 43.2 million euros (public environmental income); (b) that the total travel costs of the pickers would produce income of about 2.05 million euros; and (c), that the owners of the land, in the event that the pickers would have to pay for a permit, would obtain 109 euros per every 100 hectares in the form of private environmental income.

In addition, the increasing demand nowadays for free-time and leisure activities has boosted the emergence and development of mycological associations (Figure 5) and to a large extent thanks to them the introduction of mycotourism, a new form of tourism that combines nature and gastronomic tourism and has both direct and knock-on benefits for rural areas [37]. This type of tourism has emerged from a drive to specialize rural tourism around a particular subject or theme [102]. Although in Spain this trend emerged later than in other European countries, the initiatives so far implemented are worthy of note.

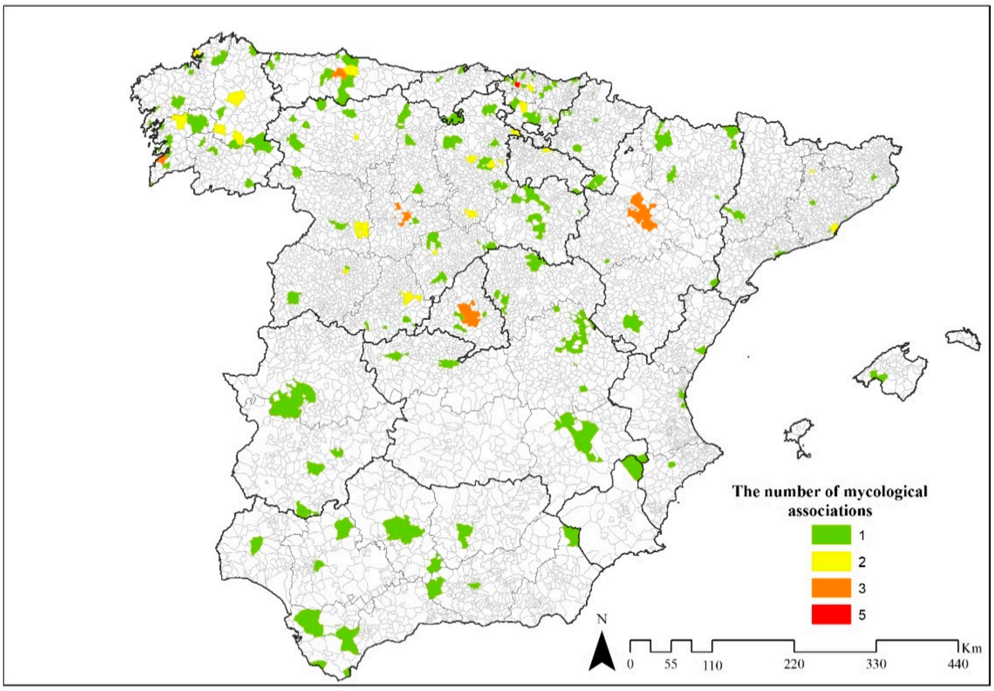


Figure 5. Distribution of the mycological associations in Spain in 2017. Source: Created during this research.

Mycological tourism has also incorporated a range of horizontal development actions that have improved the quality of the product on offer. These include for example, quality standards such as the GASTROMYAS mycogastronomic seal of quality scheme introduced in Castilla y León [102], and the drive to modernize and commercialize mycological traditions through, for example, guided routes. An excellent example of this is the MICOCYL Mycology project in Castilla y León.

Those offering mycological tourism activities in Spain have also carried out vertical development actions, which in some cases have enabled mushrooms to be more than just a complementary aspect of the main product. These include creating tourism products centred around mushrooms and mushroom-picking (for example mycological weekends, especially during the autumn season and around Valentine's Day). Other events combining mycology and tourism have also been organized, such as mycological and myco-gastronomy fairs. There were 58 such events in Spain in the 2016–2017 season, about 43% of which were held in Catalonia (Figure 6), a region with a long mycological tradition.

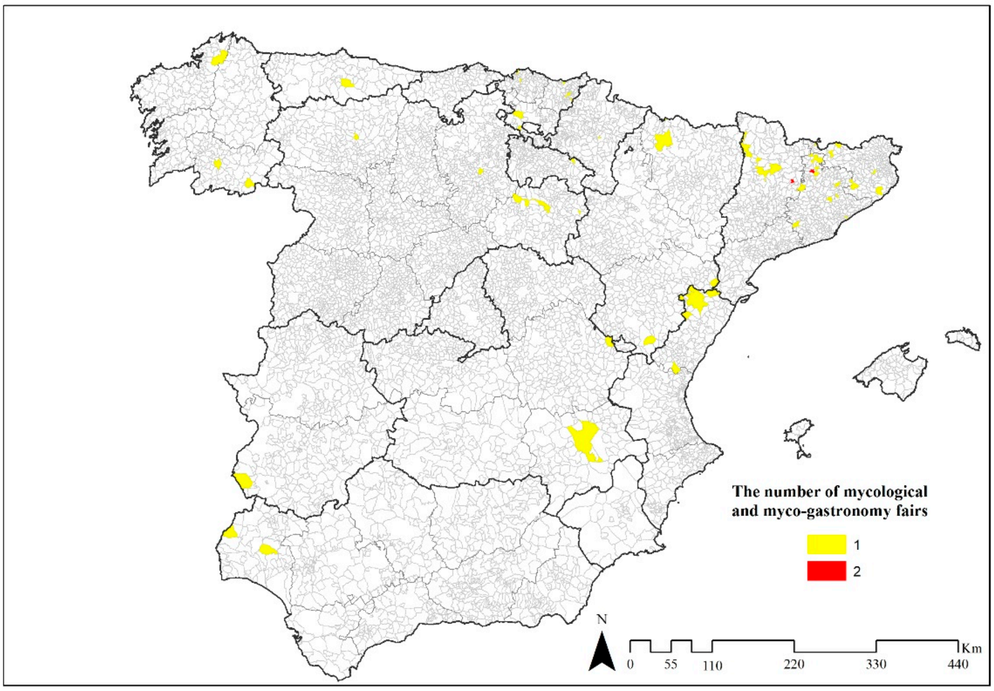


Figure 6. Distribution of mycological and myco-gastronomy fairs in Spain in the spring-autumn season 2016–2017. Source: Created during this research.

On occasions these activities are focused on one particular mushroom, as an iconic symbol of a particular region or area, such as the *Amanita ponderosa* or certain species of the *Terfezia* genus. This reinforces the identity and the popular traditions of the places where these events are held, so enabling the survival of an ancestral source of food or of income in rural communities. There is also a range of experiences in which visitors can participate in activities related with mushroom cultivation. For example, visits to the fields where truffles are farmed (as in the Sistema Ibérico) or to the towns where white button mushrooms are produced (as in La Rioja). Some of the most striking cases of rural towns specializing in mycotourism include Burgo de Osma in the province of Soria and Aracena in Huelva. The towns that want to promote mycotourism often have mycological interpretation centres or museums as part of the products or activities on offer to tourists. In Spain, we counted 23 such centres, over half of which (52%) are in Andalusia. Many of these were set up under the auspices of the Plan for the Sustainable Use and Conservation of Mushrooms and Truffles in Andalusia (Plan CUSSTA) launched in 2001 (Figure 7). These centres are often associated with shops selling mycological products, mycological fairs, markets or events, and restaurants and bars with a range of mushroom-inspired dishes.

Some areas have entered the phase of diagonal development of the range of tourism products [31], in which research, development and innovation projects (R&D projects) have been carried out with results for mycotourism: (a) the MYAS (Mycology and Sustainable Use) project in Castilla y León (the most important results of which include the creation of three mycological interpretation centres, the development of 15 mycological routes, the training of at least 40 mycological guides and the creation of a mycogastronomic seal of quality, GASTROMYAS) [71,104]; (b) the LIFE MICOVALDORBA project in Navarra (the most important results of which include the creation of mycological routes) [105]; (c) the CUSSTA Plan in Andalusia (noteworthy results include the creation of 8 mycological information points and a mycological garden, as well as two official mycological routes per province) [106]; (d), the MICODES Project, in the provinces of Albacete, Cuenca, Granada and Fuerteventura (main objectives include extending mycotourism-related activities throughout the year by encouraging rural hotels and guest houses to take part in the project and by creating signposted mycological itineraries and holding training courses for mycological guides) [107]. These initiatives and the resulting "know-how" would be easy to transfer to other regions.

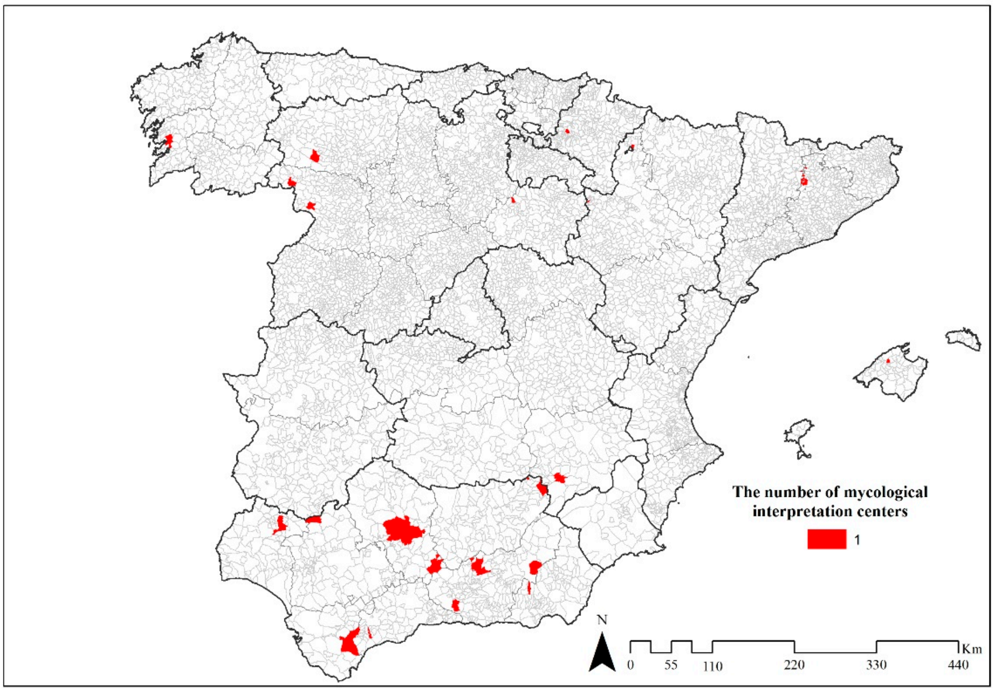


Figure 7. Mycological interpretation centres in Spain in 2017. Source: Created during this research.

As regards the demand for tourism products of this kind in Spain, a quantitative study was carried out in which they analysed the repercussions of mycological tourism, focusing above all on Castilla y León [28]. Their results showed that mycological tourism generated about 120,000 overnight stays a year in rural areas of the region (about 9% of the total for rural tourism in the region), attracting about 42,000 people. In certain areas of the province of Soria such as those belonging to the Association for the Endogenous Development of the Almazán area and other Towns (ADEMA), in good years for mushroom production, mycological tourism could account for as much as 16-17% of overnight stays [38]. These authors also estimated that mushroom pickers staying in the area contributed around 4.5 million euros a year to the regional economy.

In short, given the economic potential of wild edible fungi (as well as their ecological values), specific mushroom-related silviculture is required to conserve and enhance the mycological resources in our forests [108].

The use of mycological resources in Spain is not regulated at a national level, although the picking of wild mushrooms in woods is subject to the laws governing forests. The owner of the forest is the owner of all the forest resources it produces, such as mushrooms [109]. Some of the Spanish regions have introduced specific regulations on the use of mycological resources. These include the autonomous community of Castilla y León [110] and the Andalusian provinces of Almeria [111] and Jaén [112].

At a more local level, the use of mycological resources must be integrated into projects for the planning and organization of mountain areas [113]. The picking of wild mushrooms will have to be regulated [113], for example through public or private mycological reserves (one of the most important such initiatives in Spain is the Association of Forest Owners in Ávila, in Castilla y León), or mycological parks (such as the MICOSILVA project), in order to create greater added value in local communities and enhance their sustainable use. To this end the organizations and associations that regulate the trade and distribution in the value chain associated with the use of wild mushrooms also have an important role to play. These include for example the "Micobierzo Gourmet" Cooperative in León, and "Setas Silarche", S.L. a company based in Aracena (Huelva).

4. Conclusions

Fungi play a crucial ecological role in the management of ecosystems such as those in the Mediterranean Region, and in Spain in general. Since ancient times, people have used fungi for a variety of purposes, such that they have come to influence their beliefs and, in some cases, have become a symbol of their identity and a basic ingredient in the production of certain essential food and pharmaceutical products. In today's post-industrial and post-material world, new values and new socioeconomic potential are being assigned to these ancient products, which now offer excellent opportunities to improve the quality of life in peripheral rural areas, so halting the exodus to the cities.

Likewise, the cultivation of different kinds of fungi (epigeous saprophyte species and hypogeous ectomycorrhizal fungi) has created considerable expectations for declining rural areas. In the case of Spain, important opportunities have emerged in the cultivation of black truffles (*Tuber melanosporum*) above all in the Gúdar-Javalambre area in the Sistema Ibérico mountain range. In good years, the income from this crop per hectare of irrigated land can exceed that obtained from such profitable, albeit less sustainable, crops as greenhouse vegetables, which are cultivated in modified conditions and can have considerable environmental impact.

In addition to these new opportunities in mushroom cultivation, another interesting option is the multifunctional exploitation of forest resources and in particular wild mushroom picking, in which there has been increasing interest in recent decades in Spain and other countries. This trend is reflected not only in the food retail sector, but also in restaurants, leisure and most recently tourism. In specific cases, the returns from the combined use (described above) of this non-wood product may even exceed those earned from traditional forestry businesses such as logging [28,114,115].

The main weaknesses and threats to the country's mycological resources include global warming and the associated changes in the climate, the inherent variability of the Mediterranean climate in the Iberian Peninsula and the de facto deregulation of the use or exploitation of wild mushrooms in certain parts of Spain. As far as is possible, these threats must be addressed in order to ensure important economic, social and environmental benefits for rural Spain.

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