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Macrofungi diversity in cork-oak and holm-oak forests in Andalusia (southern Spain); an efficient parameter for establishing priorities for its evaluation and conservation

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Abstract: In this work, the fungal diversity of holm-oak and cork-oak woodlands in southern Spain is studied in order to analyse the macrofungi component and its ecological characteristics, as well as to establish priorities for its conservation. For this, we have compiled published as well as unpublished data, and applied compositional analysis and statistical methods (basic statistics, non-parametric and multivariate analyses). Priority areas were selected based on complementarity analysis. As a result, 838 taxa were recorded, 78.6% in cork-oak and 76.4% in holm-oak forests, with 55.1% in common. The ratio of mycorrhizal to saprophitic species indicated that cork-oak woodlands present a higher diversity and conservation degree of its macrofungal community than holm-oak woodlands, since the mycorrhizal component is more important for the conservation of these forests (due to nutritional relations). Both forests types appear well differentiated in the multivariate analysis. In the complementarity analysis, with only one site, we recorded 40% of the total species encountered. The percentage increased to 80% with four sites. This type of approach, by highlighting the important areas for conservation of fungal diversity, constitutes a powerful tool to optimise conservation efforts.

Keywords: Macrofungi, diversity, richness, Mediterranean woodlands, priority areas, conservation.

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1 Introduction

Andalusia (southern Spain), with a Mediterranean bioclimate, has two of the most important evergreen-oak woodlands in the western Mediterranean area: holm-oak (*Quercus ilex* subsp. *ballota*) and cork-oak (*Q. suber*) [1]. These forests are widespread and also have a significant degree of diversity, potentially occupying over 80% of the total surface of the area [2] (Figure 1). Nevertheless, today, dense woodlands occupy only 15% of surface area, 97,017 ha of holm-oak communities and 148,737 ha of cork-oak communities. Moreover, there are 323,031 ha of open woodlands (*dehesas*), mainly in the western Andalusia (Source: Consejería de Medio Ambiente; Regional Government of Andalusia).

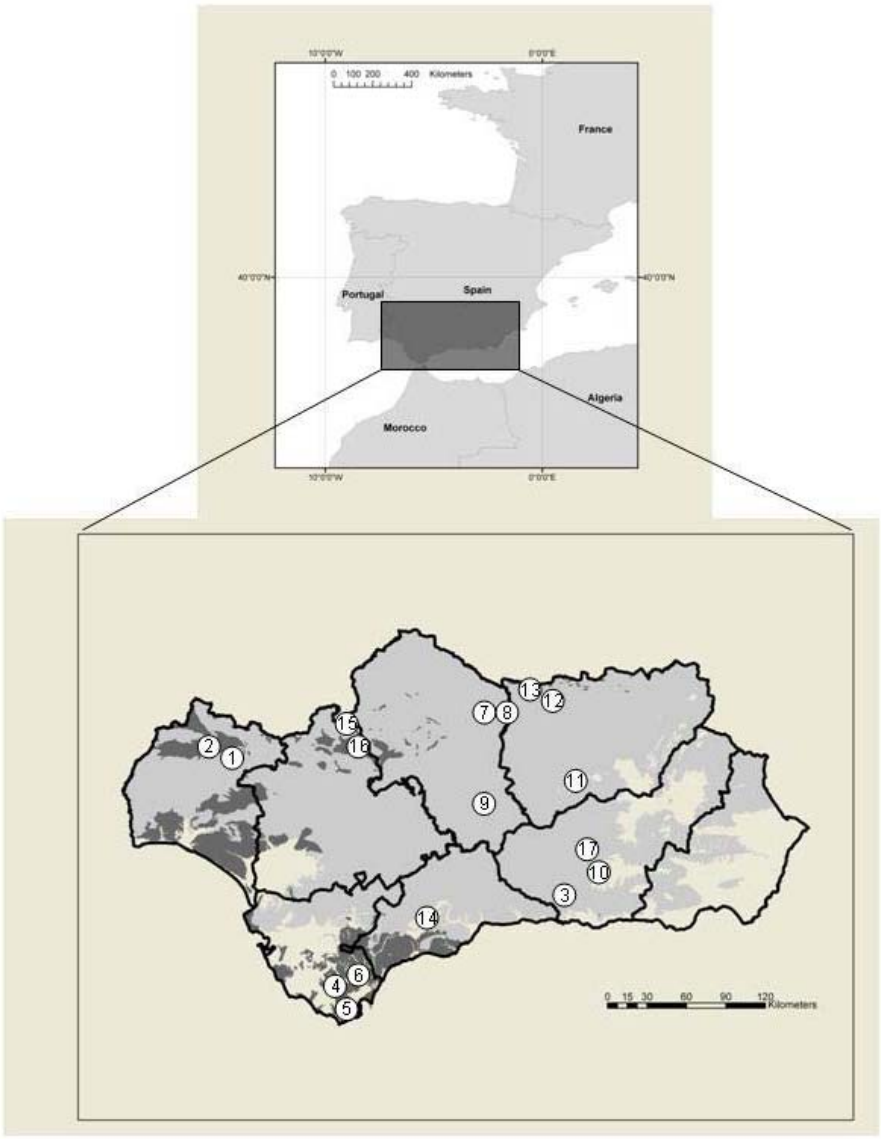

Fig. 1 Estimated potential areas of holm-oak (light grey) and cork-oak (dark grey) woodlands in the study area (adapted from [3]). The numbers indicate the selected sites (see Table 1 for details).

Biogeo.	No	Abbrev.	Protected area	Comm.	Coord.*	Substrate
1	1	A-i	Sierra de Aracena	*Q. ilex*	x=0183500 y=4207518	Siliceous
1	2	A-s	Sierra de Aracena	*Q. suber*		Siliceous
1	3	AH-i	Sierra de Tejeda	*Q. ilex*	x=0422923 y=4080114	Calcareous
1	4	AI-s	Alcornocales	*Q. suber*	x=0270038 y=4022903	Siliceous
1	5	AII-s	Alcornocales	*Q. suber*	x=02685596 y=4000306	Siliceous
1	6	CF-s	Alcornocales-Cortes	*Q. suber*	x=0276769 y=4029153	Siliceous
2	7	CM-i	Cardeña-Montoro	*Q. ilex*	x=0386865 y=4230114	Siliceous
2	8	CM-s	Cardeña-Montoro	*Q. suber*		Siliceous
1	9	CO-i	Sierras Subbéticas	*Q. ilex*	x=0383500 y=4148383	Calcareous
1	10	GU-i	Sierra Nevada	*Q. ilex*	x=0466673 y=4104153	Calcareous
1	11	JA-i	Sierra de Mágina	*Q. ilex*	x=0460423 y=4177710	Calcareous
2	12	JM-i	Sierra de Andújar	*Q. ilex*	x=0408500 y=4236364	Siliceous
2	13	JM-s	Sierra de Andújar	*Q. suber*		Siliceous
1	14	MA-i	Sierra de las Nieves	*Q. ilex*	x=0321961 y=4062806	Calcareous
2	15	S-i	Sierra Norte	*Q. ilex*	x=0258019 y=4202229	Siliceous
2	16	S-s	Sierra Norte	*Q. suber*		Siliceous
1	17	SH-i	Sierra de Huétor	*Q. ilex*	x=0459942 y=4126268	Calcareous

* UTM Coordinates of the centroids of the studied sites. Biogeo.=Main Biogeographical areas. 1=Baetic province (Baetic ranges s.l.), 2=Mariánico-Monchiquense province (Sierra Morena s.l.)

Table 1 Main characteristics of the sites studied.

For cork-oak woodlands, the optimum conditions include a rainfall regime of 600 to 1000 mm per year, some oceanicity, average temperatures of between 13-18 °C and decarbonated soils [3]. Holm-oak forests can tolerate a broader range of rainfall (with an optimum from 400 to 1000 mm), temperature and a high degree of continentality. In addition, this species can be seen over calcareous and siliceous substrates [4, 5].

From the macrofungi standpoint, many references so far has concerned about the floristic issues (as compiled [6]), while fewer treat ecological aspects of these woodland

types (e.g. [7–19]). Recently, Moreno Arroyo (2004) [6], Moreno Arroyo *et al.* (2005) [20] and Ortega and Linares (2003) [21] compiled data of a high rate of plant communities in the study area, mainly in natural protected areas of Andalusia.

In this study we address the following issues: 1) Evaluation of macrofungi richness in holm-oak and cork-oak forests in the southern Spain. 2) Application of different criteria to select priority areas, focusing on the conservation of the macrofungi richness of the vegetal communities studied in Andalusia, which covers a broad area in the Iberian Peninsula.

2 Experimental procedures

2.1 Study area

The study area was the southern Iberian Peninsula (Figure 1), located between 36° 00' and 38° 35' north latitude and 1° 35' and 7° 35' west longitude, comprises 87,597 km^2, constituting the region of Andalusia. A remarkable feature of the study area is its enormous orographical, geological, edaphic and climatic diversity, which gives rise to its floristic, phytocoenotical and phytogeographical diversity [22]. Three large morphostructural units can be distinguished: the Betic range, Sierra Morena and the Guadalquivir river depression.

Sierra Morena is the southern slope of the Iberian Meseta and simultaneously the northern border of the study area, with altitudes between 200 m.a.s.l. at the western limit (Sierra de Aracena) and more than 1,700 m.a.s.l. (Despeñaperros) on the eastern one. This unit is composed of siliceous materials, such as slates, granites and quartzites, with occasional Palaeozoic limestone outcrops.

The Betic range constitutes the southern fringe of the study area. The altitudinal range is higher ranging from sea level to the 3,482 m.a.s.l. (Mulhacén peak). Geological substrates are mainly limestones and dolomites, with extensive outcrops of siliceous materials, such as mica-schists and phyllites [23].

Finally, the Guadalquivir depression lies between the two former units, with altitudes ranging form sea level, in the marshlands of Doñana, to approximately 800 m.a.s.l. on the eastern boundary. Detrital and marly geological materials are very abundant in this region.

The entire area has a Mediterranean macroclimate, with average rainfall between 300 to 1,200 mm per year and with a broad range of temperatures [22].

Two main biogeographical zones were established according to Rivas-Martínez *et al.* (1997) [22], which reflect in the general distribution of mycobiota [14] (see Table 1).

2.2 Data collection

Selected areas were located throughout Andalusia, and mainly in the natural protected areas (see Figure 1 and Table 1). Consequently, conservation degree of its plant communities is quite good, and also reflects the phytogeographical heterogeneity of the study

area [14]. Over 50% of the data stem from one of the authors (A.O.), collected over the last 30 years, while the rest have been compiled from the literature on Andalusian mycobiota. Moreno Arroyo (2004) is particularly noteworthy, compiling all the previous bibliographic references, including the results of the study made by a major Spanish mycologist group (see [6]) working on the mycobiota from many Andalusian geographical areas. Many of these areas coincide with the study area in the present work. The sampling method complies with that of Ryvarden (2000) [24] and consists of collecting the basidiomata in the proper seasons (autumn and spring). All the included areas have been sampled for at least three years, with seven visits per year, although we have compiled of almost all the areas, data taken irregularly (mainly from bibliographic sources) since 1980 to date. All the compiled data (both bibliographic and field data) were included in a database (unpublished), covering the macrofungi from Andalusian holm-oak and cork-oak forests. This database was used for the present study. We estimated that our checklist includes approximately 90% of the mycobiota of holm-oak and cork-oak woodlands in southern Spain (according to [6] and [14]). The macrofungi nomenclature is based on Kirk and Ansell (1992) [25] as well as the web site of CABI Bioscience Databases (http://www.speciesfungorum.org/Names/Names.asp). Nutritional modes (mycorrhizal or saprotrofic) of the species here studied, were made according to the UNITE database (http://unite.ut.ee) [26]. Species are grouped in traditional morpho-groups in order to facilitate the understanding for non-mycologist readers (see Appendix 1). Species nomenclature was established according to Legon and Henrici (2005) [27] and Moreno-Arroyo (2004) [6]. However, we are aware of the fact that our approximation is based on fruiting-bodies, thus species with lack- or nonconspiceous sporocarps will be missed [28]. The application of high-resolution molecular tools, that allow identification of individual mycorrhizas, represent a significant methodological advance for this purpose [29]. Unfortunately detailed information using this type of approach is very scarce and can only cover small areas (see [28], for further details on this topic), consequently is not useful to achieve the objectives of this work.

Throughout the text, the term “diversity” was used as in Magurran (1988) [30].

2.3 Statistical analysis

With the species presence/absence data by study sites, we performed a matrix with 17 columns and 838 rows (available from the authors). The relationships between the different sites were established by indirect-gradient analysis, namely Detrended Correspondence Analysis (hereafter DCA; [31]), using the statistical package CANOCO [32], with non-transformed data and down-weighting rare-species options. The relationships between pairs of independent variables such as substrate, type of forest (holm-oak/cork-oak) or phytogeographical unit were tested using the non-parametric Mann-Whitney U-test. This and other basic statistical analyses were performed with the SPSS 12.0 package (SPSS Inc., Chicago, Illinois). Finally, the similarity index of Jaccard (1908) [33] was used to reflect the resemblance between types of forests, according its mycorrhizal:saprotroph ratio.

2.4 Selection of priority areas

To establish important sites for the conservation of macrofungi richness in holm-oak and cork-oak woodlands, we used the following concepts: i) Richness (Ri): number of taxa present at each site, as representative of diversity [34]. ii) Continuous rarity (Rc) [35, 36]: this is based on the level of stenochory of each taxa. Thus, a taxa found only at a single locality will have a greater degree of rarity than the one found at various localities. The inverse of the number of localities gives a good estimate of this degree [37]. Following this procedure and adding together the values for each taxa of those present in a territory, we get an overall value (criterion of discontinuous rarity). iii) Discontinuous rarity or threshold rarity (Rd): In the first step, we recorded the number of localities in which each taxon considered was present, while in the second step we took 25% of the rarest taxa (i.e. beginning with taxa that appear in the lowest number of localities). The discontinuous rarity reflects how many taxa within this "rare taxa" (25% least represented), are present at each site or locality [36, 37] (i.e. if one site present six taxa within the "rare taxa", as defined above, the Rd=6). iv) Principle of complementarity (Com) [38, 39]: this takes into account how the addition of a new locality influences the total number of elements (i.e. taxa in this work) compiled [40, 41].

This type of analysis enables us to evaluate the relative importance of each study area and how it contributes to the conservation of the fungal diversity. In short, we aim to show how a maximum number of taxa can be conserved on a minimum surface area. Complementarity analysis is not placed in opposition to criteria mentioned earlier (Ri, Rc and Rd), since these can serve as the basis for selecting the first locality. Thus, we can use both richness [38] as well as rarity [39] in the complementarity criterion iterative process.

3 Results

3.1 Macrofungi richness and diversity

In the woodlands studied, the total number of macrofungi species was large (838 taxa). The holm-oak forests registered a similar percentage of species (76.4%) as cork-oak forests (78.6%). Both ecosystems had a considerable percentage of taxa in common (55.1%).

For the established morpho-groups the more noteworthy results are:

AGARICS: The relative number of agarics was greater in holm-oak forests than in cork-oak ones (2.4% *vs.* 77.6%), as it was for the proportional representation of exclusive species (22.4% *vs.* 17.5%). This fact was significant in the case of the genus *Cortinarius* (Pers.) Gray, since its representation was larger in holm-oak forests (81.1% *vs.* 73%), owing to the exclusive presence in calcareous soils of several typical taxa (*e.g.* *C. calochrous* (Pers.) Fr. group, *C. decipiens* var. *subturibulosus* (Kizlik) A. Ortega & Mahiques and *C. ionochlorus* Maire). Also, there was a higher significance in calcareous holm-oak forests, of several *Hygrophorus* Fr. species (*e.g.* *Hygrophorus roseodiscoideus*

Bon & Chevassut). On the contrary, the richness of *Amanita* Pers., *Hebeloma* (Fr.) P. Kumm. and *Tricholoma* (Fr.) Staude species was greater in the cork-oak forests. In the case of saprophyte species, the differences were less pronounced, except for the genus *Lepiota* (Pers.) Gray (73.1% *vs.* 46.1%) and *Mycena* (Pers.) Roussel (83.3% *vs.* 72.2%), which were more abundant in the holm-oak forests and *Pleurotus* (Fr.) P. Kumm. (25% *vs.* 100%), which was found to be more abundant in cork-oak forests.

APHYLLOPHORACEOUS FUNGI: Owing to the higher proportional representation of lignicolous taxa (e.g. *Hyphoderma* Wallr., *Peniophora* Cooke, *Phanerochaete* P. Karst. species), their richness was greater in the holm-oak woodlands, since these leave abundant decomposing plant litter over the soil and their wood is easier than cork-oak wood for the fungi to decompose [13]. The exception was *Botryobasidium laeve* (J. Erikss.) Parmasto and *B. subcoronatum* (Höhn. & Litsch) Donk, which were present only over the branches and trunks of *Quercus suber*. The terricolous aphyllophoraceous fungi (e.g. *Chantharellus* Fr., *Ramaria* Fr. *ex* Bonard., *Sarcodon* Quèl. *ex* P. Karst. species) have different ecological characteristics. They are more abundant in the cork-oak forests, which have a biogeographical and substrate characteristics favourable for the macrofungi to fruitify [14].

BOLETES: The bolete richness was less in the holm-oak forests than it was in the cork-oak woodlands (80.4% *vs.* 87%). The relative number of common species was notable (67.4%), and the numerical distribution of exclusive species was lower in the holm-oak than in the cork-oak communities (13% *vs.* 19.6%).

GASTEROID FUNGI: Every gasteroid fungus had a similar representation level except the *Geastrum* Pers. species (holm-oak woodlands: 100% *vs.* cork-oak forests 25%). A possible explanation could be the considerable degree of adaptation of these species to the Mediterranean area.

RUSSULALES: The represented species of the *Russulales* have particular ecological characteristics, since they (fundamentally *Russula* Pers.) are more frequent in the cork-oak forests (100%) than in the holm-oak woodlands (47.4%). Many of the *Russsulales* taxa are exclusively found in cork-oak forests (52.5%). One explanation is the considerable oceanicity and the acidity of the substrates from the distribution area of the *Quercus suber*. These circumstances highly influence the fructification of the genera *Russula* Pers. and *Lactarius* Pers. [14].

The mycobiota from both woodlands are numerically quite similar except for differences related to the presence of lignicolous aphyllophoraceous fungi, which are more frequently found in the holm-oak forests. On the other hand, the genera *Russula* Pers., is well represented in the cork-oak forests.

We established floristic affinities between the different localities studied (Table 2). We also studied the way in which the forests and substrate types influence the local macrofungi flora (see ecological-characteristics section). On these data, we calculated the Jaccard index (Figure 2). The most significant results are explained below.

HOLM-OAK FOREST: The similarity degree was 20% (J = 0.20±0.01). Siliceous holm-oak forests were more heterogeneous (J = 0.19±0.03), while the calcareous holm-oak forests were more homogeneous (J = 0.28±0.01). The latter represents a quite restrictive

ecosystem for the fungi to prosper, resulting in a higher number of species that could only be found in the holm-oak forests.

	Q. ilex	*Q. suber*	Common	Exclusive *Q. ilex*	Exclusive *Q. suber*
Total	659	640	462	199	178
AGARICS	416	391	303	113	88
APHYLLOPHORACEOUS	128	103	63	65	40
BOLETES	37	40	31	6	9
GASTEROIDS	33	28	24	9	4
RUSSULALES	35	78	42	3	36

Table 2 Richness of *Q. suber* and *Q. ilex* with respect to the main macrofungi groups.

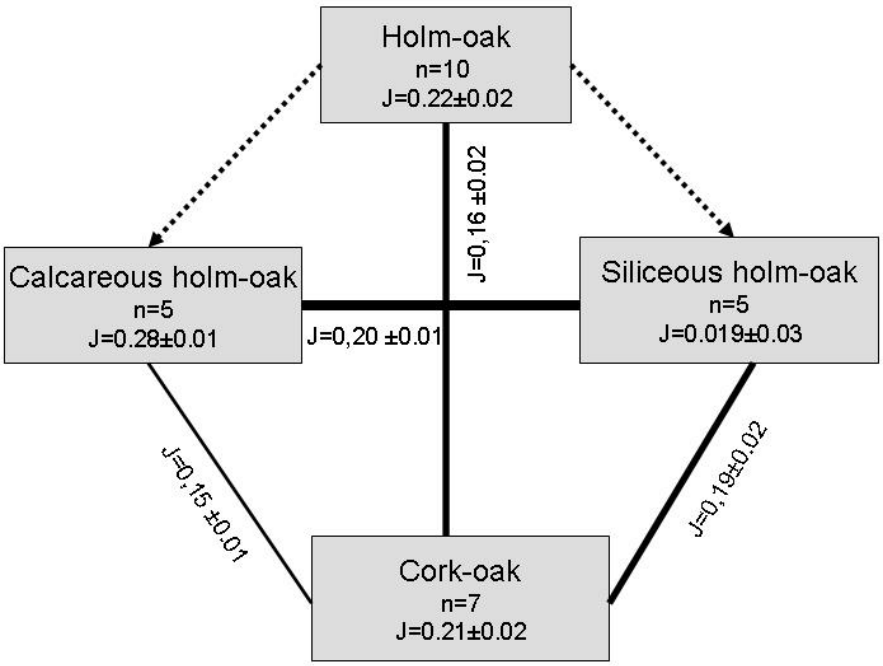

Fig. 2 Diagram showing similarities (J=Jaccard index) in mycorrhizal:saprophitic ratio between groups (woodlands types). n=number of study sites included in each group.

CORK-OAK FORESTS: The Jaccard index was 0.21±0.02. This is quite similar to that of the holm-oak forests, but in this case all localities were more homogeneous, since all had a siliceous substrate.

HOLM-OAK *vs.* CORK-OAK FORESTS: The inter-similarity degree was 16% (J = 0.16±0.02), but the Jaccard index indicated differences among siliceous holm-oak *vs.* cork-oak forests (0.19±0.02) as opposed to calcareous holm-oak *vs.* holm-oak woodlands (0.15±0.01). These results reflect the significant influence of the substrate (calcareous-carbonate vs. siliceous or decarbonated).

3.2 Ecological characteristics of the macrofungi flora

The relationship between mycorrhizal *vs.* saprophytic species could constitute a real parameter for measuring the degree of maturity and the level of conservation for certain communities [14, 42, 43]. The ectomycorrhizal fungi dominated in number over the saprophytic species when the forest was healthy [16, 19, 44].

	Quercus ilex subsp. *ballota*									
Sites	AH-i	GU-i	SH-i	JA-i	MA-i	CO-i	A-i	CM-i	JM-i	S-i
mycorrhizal	59	33	74	100	37	88	103	126	78	31
saprophytic	104	58	92	119	79	134	118	172	89	51
ratio	0.57	0.57	0.8	0.8	0.47	0.66	0.9	0.73	0.88	1

	Q. suber						
Sites	A-s	AI-s	AII-s	CF-s	CM-s	JM-s	S-s
mycorrhizal	226	152	112	53	99	55	56
saprophytic	174	150	92	51	96	39	66
ratio	1.3	1.01	1.22	1.04	1.031	1.41	0.8

Table 3 Mycorrhizal and saprophytic richness, and the mycorrhizal:saprophitic ratios of the selected sites.

As shown in Table 3 the cork-oak forests had a larger mycorrhizal/saprophytic quotient (0.85-1.41, mean 1.12), while in the holm-oak woodlands it was less than one (0.47-0.88, mean 0.7). Also meaningful was the mycorrhizal/saprotroph relationship of the species collected from the Betic range (0.47-0.84, mean 0.65), in contrast to those in the Marianico-Monchiquense and Aljíbico chorological sectors (0.61-1.41, mean 0.96). Also, a comparison between siliceous and calcareous woodlands showed that important differences can be established (0.57-1.41, mean 0.91 in siliceous and 0.47-0.84, mean 0.63 in calcareous ones).

There were three different factors analysed influencing the mycorrhizal and/or saprotroph richness. The first one is the community types, the holm-oak or cork-oak forests. There was a significant difference (U=4.00; df=16; p= 0.001) between the two types of forest. The forest type represents an important factor for species distribution. The second factor was the biogeography (U=6.00; df=16; p= 0.005). The third factor refers to the siliceous or calcareous substrates, differences in this case were less significant (U=6.50; df=16; p= 0.009).

Also noteworthy were the relationships between the mycorrhizal and the saprotroph species present in both forests. In our case, these quotients were: mycorrhizal species in *Q. suber* / *Q. ilex* mycorrhizal species = 1.25, while the saprophytic relationship were 0.81.

These data confirm that the cork-oak forest are conserved better than the holm-oak forests.

3.3 Multivariate analysis

Figure 3 indicates that, taking into account the macrofungal composition (presence/absence data), two groups can be established within the studied areas. The first group located at the bottom left, exclusively includes calcareous holm-oak woodlands. The second one includes the whole set of siliceous holm-oak and cork-oak forests. Although siliceous holm-oak woodlands show floristic affinities with calcareous ones, as demonstrate their position in the left part of the siliceous group. In summary, along the first axis, which explains a higher percentage of variance (13.2%), we can identify an east-west geographical gradient, which agrees with calcareous/siliceous gradient and increasing temperature and rainfall gradient.

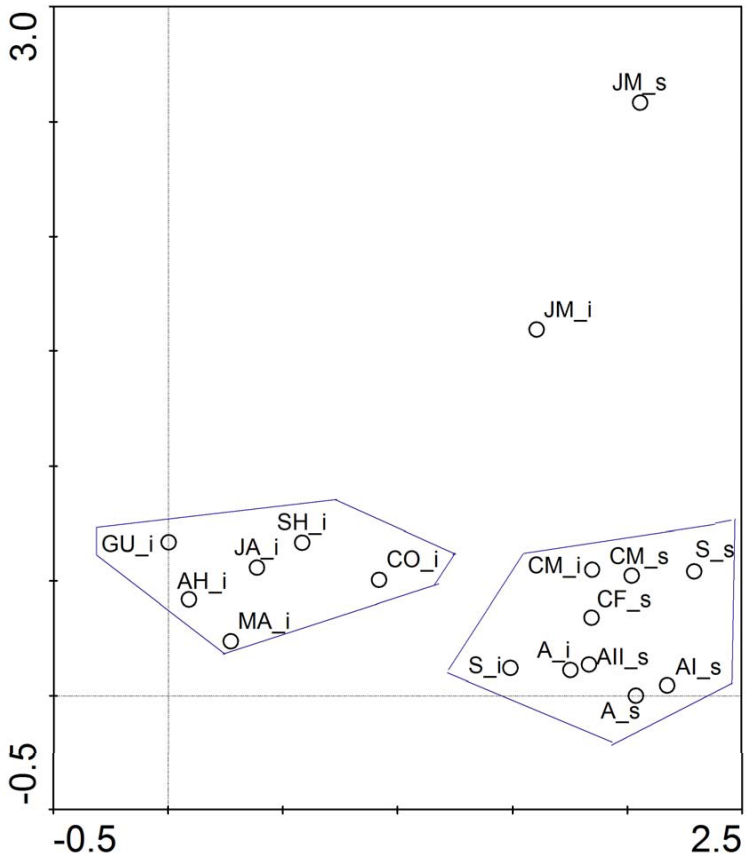

Fig. 3 DCA plot of the study sites. X-axis: eigenvalue 0.346, % of variance 13.2; Y-axis: eigenvalue 0.205, % of variance 7.9%.

3.4 Complementarity analysis

Complementarity analysis (see Table 4), shows that the cork-oak communities of the western part of the study area (A-s) have the richest species diversity, with 400 taxa, signifying over 50% of the total account. Next, a second group (JA-i, AI-s y CM-i) contributes with more than 60 new taxa per locality. The addition of this group increases

the number of species to over 677 (up to 80%). The rest of the sites contribute in a range from 44 to 0 taxa. In order to account for the overall macrofungi diversity of southern Spain, we needed to include 16 of the 17 studied areas. Note that CM-s with notable richness (195 taxa), added no original (meaning not included in other studied area) taxa. If sites are selected according to rare species (see Rd values in Table 4), the result (with same exceptions; e.g. CO-i, where Rd=20) is almost the same.

Site	Ri	Rc	Rd	Com
A-s	400	2136.73	37	400
JA-i	219	1106.44	23	118
AI-s	302	1596.98	26	109
CM-i	298	1171.37	10	60
CO-i	222	1047.72	20	44
AII-s	204	1022.12	18	35
AH-i	163	784.77	15	26
SH-i	166	741.25	12	19
A-i	221	925.41	11	13
JM-i	167	659.6	8	11
S-s	122	508.37	7	10
MA-i	116	464.68	6	6
CF-s	104	416.7	5	5
S-i	82	307.51	5	5
JM-s	94	372.6	4	4
GU-i	91	314.34	3	3
CM-s	195	649.89	0	0

Table 4 Selection of priority areas according to: richness (Ri), continuous rarity (Rc), discontinuous rarity (Rd) and complementarity (Com) of the sites sampled (see Table 1 for further explanation). Note that selected sites are organized according their complementarity values (Com.).

4 Discussion

The macrofungi diversity in Andalusian holm-oak and cork-oak forests is numerically quite similar, but the floristic components are different, since the *Q. suber* forests have higher mycorrhizal species richness, while the *Q. ilex* woodlands have a higher relative number of saprotroph macrofungi.

Possible explanations are: (1) The effects of localities where cork-oak and siliceous holm-oak forests grow and the effects of convergence from ecological factors such as the greater oceanity and the siliceous substrates. The degree of oceanity, influenced by the geographical position, is characterized by heavier rainfall and the milder mean temperatures. These factors encourage mycorrhizal macrofungi to fruitify [14]. There is consider-

able oceanicity in the areas located on Marianico-Monchiquense and Aljíbico chorological sectors, resulting in greater mycorrhizal fungi richness. (2) The holm-oak forests located in the Betic range (Malacitano-Almijarense, Nevadense and Subbetic chorological sectors) have several common ecological factors, such as relative continentality and the calcareous substrates. The degree of continentality is characterized by a lower rainfall regime and a broader temperature gradient, with significant differences between summer and winter temperatures. Although mycorrhizal macrofungi fruitify are scarcer; nevertheless, a representative number of ectomycorrhizal species are specific to these forests.

Hence, the considerable macrofungi richness of Andalusian woodlands makes forest-conservation necessary for the following reasons: (1) The cork-oak forests would be an important source of Mediterranean mycodiversity for mycorrhizal species (*e.g.* *Amanita* Pers., *Boletus* Fr., *Russula* Pers. and *Tricholoma* (Fr.) Staude). These fungi are key species in the development, equilibrium and conservation of the forest communities. (2) Compared to cork-oak, *Q. ilex* forests present a less satisfactory conservation level despite the presence of a significant cohort of mycorrhizal specific taxa from Mediterranean calcareous holm-oak forests. Mycorrhizal component is more important for conservation than is the saprotrophic one, because the first component favours water and ionic absorption [45, 46] and the latter may represent a source of potential pathogens under the conditions of forest decline, promoting a dieback phenomena (e.g. [47–49]).

Despite considerable gaps in the knowledge of the group, we want to emphasize that the current study forests are home to some of the rare and/or endangered taxa included in the draft of European Red List of Fungi [50], such as *Cortinarius ionochlorus* Maire, *Cantharellus melanoxeros* Desm. and *Podoscypha multizonata* (Berk. & Broome) Pat. In addition, some recorded taxa are scheduled for inclusion in a forthcoming Regional Red List of Fungi (A.O., unpublished data), such as: *Amanita bellei* (Beanseign.) Bon & Contu, *A. singeri* Bas., *Boletus edulis* Bull., *B. pseudoregius* (Huber) Estades, *B. pulchrotinctus* Alessio, *Entoloma bloxamii* (Berk. & Broome) Sacc., *E. cedretorum* (Romagn. & Riousset) Noordel. and *Xerula xeruloides* (Bon)Dörfelt.

4.1 Priorities for conservation

For conservation priorities, we conclude that the western part of Andalusia presents higher diversity than the eastern part. Siliceous substrates show the same behaviour, so as the cork-oak forests, presenting a high richness and more originality than do the holm-oak ones. A second original core area appears in the sierras close to strait of Gibraltar. On the other hand the eastern areas, which are colder, drier and more continental and feature mainly calcareous substrates, have less conservational interest. A large percentage of mycofloristic richness (80%) can be preserved by an effective conservation of only four areas. The enormous richness and the great heterogeneity of the study area is elf evident as one needs to protect 16 of the 17 study sites in order to cover the whole species diversity. Even if the selection of priority areas were to be made according to the occurrence of rare taxa (see “complementarity analysis” in the Results section), the results would almost be

the same. This represents an important finding for establishing conservation policies, in that the richness, originality and rarity coincide in the same area.

Despite that this type of approximation, based on priority areas, is widely accepted and used in conservation strategies [51, 52], as far as we know, it has not been used formerly to establish conservation priorities for mycobiota. The main reason is that this component of biodiversity is poorly understood, and in many cases represents an important gap in the biodiversity knowledge.

In many studies focusing on the topic of species diversity and conservation such as, flowering plants (e.g. [53]), or the intersection of areas of high endemism and threat (e.g. [52]), are used to establish "hotspots". However it is known that the diversity of some groups is not always correlated with the diversity of other groups (e.g. [54]). Yet, in this work, we found that, the most important areas for the conservation of mycobiota are areas with a few number of endemic vascular-plant species [55].

We should emphasize the importance of updating the biodiversity check-list, such as the one in the Regional Government of Andalusia, in order to compile a complete database of the macrofungi richness within the network of natural protected areas.

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Appendix

Richness of the main groups and genera in the selected areas. For abbreviations of the selected areas see Table 1.

	Q. ilex										*Q. suber*							Total
	AH-i	**GU-i**	**SH-i**	**JA-i**	**MA-i**	**CO-i**	**A-i**	**CM-i**	**JM-i**	**S-i**	**A-s**	**AI-s**	**AII-s**	**CF-s**	**CM-s**	**JM-s**	**S-s**	**Taxa**
Total	175	93	176	236	126	248	266	344	186	97	481	268	248	110	233	109	143	838
AGARICS	89	62	123	147	71	131	122	188	111	45	235	180	117	68	119	62	73	504
Agaricus	1	1	2	3	1	4	7	5	5	2	12	8	0	1	3	1	1	21
Agrocybe	0	0	0	0	0	0	0	2	2	0	0	1	1	0	0	1	0	4
Amanita	2	0	5	6	3	8	23	16	19	8	32	17	11	7	9	8	12	42
Armillaria	0	1	1	3	1	1	1	2	0	1	2	3	2	2	2	0	1	4
Clitocybe	3	3	8	6	4	5	5	9	4	1	8	10	3	5	5	3	4	17
Clitocybula	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	1
Clitopilus	1	0	1	0	0	1	1	1	1	0	1	1	1	0	1	0	1	1
Collybia	0	1	0	0	1	0	0	2	0	0	1	0	0	0	2	0	0	2
Conocybe	0	0	2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2
Coprinus	0	0	1	2	0	6	2	7	0	0	4	3	1	1	3	0	0	13
Cortinarius	22	16	25	32	8	17	15	12	12	2	33	15	18	8	12	11	4	74
Crepidotus	4	1	3	2	3	2	0	4	2	0	2	2	3	0	0	0	2	9
Crinipellis	0	0	0	0	0	1	1	1	1	0	1	1	1	0	1	1	0	2
Cyphellopsis	1	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	1
Cystoderma	0	0	0	0	0	1	2	2	0	0	2	0	0	0	2	0	0	2
Cystolepiota	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Cystophora	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1
Entoloma	2	3	2	3	1	6	6	10	6	3	11	11	4	3	7	1	6	21
Flammulaster	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1
Galerina	0	0	2	0	1	0	0	1	0	0	0	0	0	0	1	0	0	2
Geopetalum	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Gerronema	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Gymnopilus	0	0	0	0	0	0	1	1	0	0	2	1	1	1	1	1	1	2
Gymnopus	2	4	6	4	3	2	1	3	0	1	3	4	3	0	2	0	1	10
Hebeloma	3	3	5	3	3	4	2	5	3	1	4	6	3	2	5	2	1	9
Hemimycena	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Hohenbuehelia	0	0	0	0	0	0	1	0	1	0	2	0	0	0	0	1	0	2
Hydropus	0	0	0	0	0	0	0	1	1	0	1	1	1	0	0	0	1	1
Hygrocybe	0	0	1	4	0	4	3	6	2	1	5	4	2	1	5	0	0	8
Hygrophorus	5	1	5	9	6	5	3	5	4	0	6	5	3	2	5	4	1	12
Hypholoma	1	0	0	1	0	0	0	1	0	0	1	0	0	1	1	0	0	1
Inocybe	8	6	9	19	4	8	5	19	6	1	15	15	21	5	12	5	5	43
Laccaria	2	0	2	1	0	0	1	2	1	1	5	3	2	2	1	1	1	6
Lentinellus	0	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0	0	1
Lentinus	0	0	0	0	0	1	0	1	0	0	1	0	0	0	1	0	1	1
Lepiota	1	1	1	3	1	8	7	11	4	2	6	8	5	0	3	2	2	21
Lepista	1	0	0	2	1	2	5	2	2	0	5	5	2	3	2	1	2	9
Leucoagaricus	0	0	0	0	1	1	1	1	1	1	2	0	1	0	0	1	0	5

	Q. ilex										*Q. suber*							Total
	AH-i	**GU-i**	**SH-i**	**JA-i**	**MA-i**	**CO-i**	**A-i**	**CM-i**	**JM-i**	**S-i**	**A-s**	**AI-s**	**AII-s**	**CF-s**	**CM-s**	**JM-s**	**S-s**	**Taxa**
Leucopaxillus	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	1
Lyophyllum	1	0	1	2	1	3	2	1	1	0	4	1	1	1	0	2	0	6
Macrocystidia	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	1
Macrolepiota	0	2	2	2	2	4	2	3	1	3	4	3	4	0	1	0	1	6
Marasmiellus	0	0	0	1	0	0	0	1	1	0	1	0	0	0	1	0	0	2
Marasmius	1	2	3	2	1	2	3	3	3	2	0	0	0	1	1	1	0	5
Melanoleuca	0	0	1	1	0	2	1	5	2	0	2	0	1	0	4	0	0	5
Mycena	13	7	13	10	16	10	4	12	6	3	10	19	5	6	5	2	3	36
Omphalina	0	0	0	0	0	0	0	3	2	0	1	0	0	0	0	0	0	3
Ossicaulis	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Panaeolus	0	0	1	0	0	0	1	1	0	0	1	1	0	0	0	0	0	1
Panellus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Phaeomarasmius	2	1	2	2	1	1	1	1	0	1	1	0	0	1	0	0	1	2
Pholiota	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1
Pleurotus	0	0	0	1	0	0	0	0	0	0	1	1	3	0	0	0	2	4
Pluteus	4	0	1	3	0	1	2	1	3	1	4	6	4	3	2	3	4	13
Psathyrella	1	0	1	2	0	1	1	3	0	2	4	5	1	0	1	0	1	7
Pseudoclitocybe	1	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	2
Resupinatus	1	0	0	0	0	1	1	1	0	1	1	0	0	0	0	0	0	1
Rhodocollybia	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1
Rhodocybe	0	0	2	1	0	1	0	1	0	0	1	0	0	1	1	0	0	2
Rickenella	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	1	1
Roridella	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1
Sericeomyces	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Simocybe	0	0	0	2	0	1	0	0	1	0	2	0	0	0	0	1	1	3
Stigmatolemma	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Stropharia	0	0	0	1	0	1	0	1	0	0	2	0	0	0	1	0	2	2
Tricholoma	3	4	8	6	4	8	4	9	7	1	20	10	3	7	8	8	6	28
Tubaria	0	2	2	1	1	2	0	3	1	1	1	2	0	0	2	0	2	4
Volvariella	0	0	0	0	0	0	1	2	1	2	2	1	0	0	2	0	1	3
Xeromphalina	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Xerula	0	0	2	2	0	1	0	0	0	0	0	0	0	0	1	0	0	2
APHYLLOPHORACEOUS	56	16	26	43	27	43	36	44	26	15	66	40	28	23	25	13	23	169
Abortiporus	0	0	1	1	0	0	0	1	0	0	0	0	0	1	0	1	0	1
Albatrellus	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Aleurodiscus	2	0	0	0	1	0	1	1	0	1	1	0	0	0	0	0	0	2
Antrodiella	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0	1
Athelia	4	0	0	1	1	0	1	0	1	0	1	0	0	0	0	0	0	6
Atheliopsis	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Bjerkandera	0	0	0	0	0	1	0	0	0	0	1	1	1	1	0	0	0	1
Botryobasidium	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	1	0	3
Brevicellicium	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Byssomerulius	1	1	0	1	1	1	1	1	1	1	1	0	1	0	0	0	0	1
Cantharellus	1	0	0	0	0	2	0	2	1	0	5	3	2	2	2	1	0	7
Cerrena	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1
Clavaria	0	0	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	2

	Q. ilex										*Q. suber*							Total
	AH-i	**GU-i**	**SH-i**	**JA-i**	**MA-i**	**CO-i**	**A-i**	**CM-i**	**JM-i**	**S-i**	**A-s**	**AI-s**	**AII-s**	**CF-s**	**CM-s**	**JM-s**	**S-s**	**Taxa**
Clavariadelphus	0	0	1	1	0	2	2	1	0	0	2	2	2	2	1	0	0	2
Clavulina	0	0	2	1	0	1	0	3	0	2	3	1	1	0	2	0	1	3
Clavulinopsis	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Coltricia	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
Coniophora	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	1
Coriolopsis	1	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	1	1
Craterellus	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	0	1	1
Cristinia	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cylindrobasidium	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Dacryobolus	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Daedalea	0	0	1	0	0	0	0	1	0	1	0	1	0	0	1	0	0	1
Dichomitus	0	0	0	0	1	0	1	1	1	0	1	0	1	0	0	0	0	1
Fomes	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1
Ganoderma	1	0	0	1	1	3	2	1	1	0	1	1	0	0	0	1	1	3
Gelatoporia	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Globulicium	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Gloeocystidiellum	1	1	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Gloeoporus	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1
Grifola	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1
Hapalopilus	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1
Hydnellum	0	0	0	0	0	0	1	2	1	0	2	2	0	0	1	0	1	3
Hydnum	0	0	1	3	0	3	0	1	0	0	2	0	0	1	1	0	0	3
Hymenochaete	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Hyphoderma	2	2	0	2	0	0	1	1	1	0	0	0	0	0	0	0	0	4
Hyphodermella	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Hyphodontia	0	0	0	2	1	0	2	0	1	2	0	0	0	0	0	0	1	6
Inonotus	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1
Irpex	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Laeticorticium	3	2	0	3	2	1	1	0	0	0	0	0	2	0	0	0	0	3
Laxitextum	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1
Lenzites	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Macrotyphula	1	1	1	1	0	2	0	0	0	0	2	0	0	0	0	0	0	2
Melzericium	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Meripilus	0	0	0	0	0	1	0	1	1	0	1	1	0	0	1	1	1	1
Merulius	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	0	1	1
Mycoacia	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Oxyporus	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
Peniophora	8	3	2	7	5	4	2	3	0	1	1	3	3	1	0	0	0	11
Phanerochaete	1	0	0	2	0	1	2	3	0	1	0	1	0	1	1	0	0	5
Phellinus	1	2	1	2	0	2	1	2	2	2	0	0	0	0	1	1	0	4
Phellodon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Phlebia	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Phlebiopsis	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Phylloporia	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1
Podoscypha	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1
Polyporus	0	0	1	0	1	1	1	1	1	0	2	0	2	0	0	1	0	3
Pseudocraterellus	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	1	0	1

	Q. ilex										*Q. suber*							Total
	AH-i	**GU-i**	**SH-i**	**JA-i**	**MA-i**	**CO-i**	**A-i**	**CM-i**	**JM-i**	**S-i**	**A-s**	**AI-s**	**AII-s**	**CF-s**	**CM-s**	**JM-s**	**S-s**	**Taxa**
Pterula	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Pulcherricium	1	0	0	1	1	1	1	1	1	0	0	1	0	0	1	0	0	1
Pycnoporus	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1
Radulomyces	0	0	0	0	0	1	1	1	1	0	1	1	1	0	1	1	1	2
Ramaria	0	0	2	0	0	1	0	1	0	1	8	6	0	6	0	0	1	13
Ramariopsis	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	1
Sarcodon	1	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	1	5
Sarcodontia	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Scenidium	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1
Schizophyllum	1	0	0	0	0	1	1	1	1	0	1	0	0	0	1	0	1	1
Schizopora	1	0	0	0	1	0	1	1	1	0	1	1	1	1	0	0	1	1
Scytinostroma	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Sistotrema	2	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1
Skeletocutis	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Spongipellis	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1
Steccherinum	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1
Stereum	3	2	2	2	2	2	2	2	2	1	2	2	1	2	0	0	1	4
Telephora	1	0	1	0	0	0	0	2	1	0	0	0	0	0	2	0	0	2
Trametes	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1
Trichaptum	1	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1
Typhula	0	0	1	0	0	0	0	1	0	0	1	1	1	1	1	1	1	1
Vuilleminia	3	1	1	1	0	1	0	1	0	0	1	0	0	0	0	0	0	5
Xenasma	2	0	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	2
BOLETES	9	2	8	10	7	14	23	16	9	11	32	17	15	1	13	4	11	46
Aureoboletus	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1
Boletus	2	0	3	5	4	6	9	8	4	6	16	7	6	0	7	1	8	24
Chalciporus	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1
Gyroporus	0	0	1	0	0	1	1	1	1	0	1	1	1	0	1	1	0	1
Leccinum	1	0	1	2	1	2	2	1	0	1	2	1	1	0	1	0	0	2
Omphalotus	1	1	1	1	1	2	2	1	1	0	1	1	1	0	1	1	0	2
Paxillus	0	0	0	0	0	0	1	1	0	0	1	0	0	0	1	0	1	1
Xerocomus	5	1	2	2	1	3	7	4	3	4	9	6	6	1	2	1	1	14
GASTEROIDS	6	11	7	12	8	20	18	20	11	7	18	16	15	7	13	4	5	37
Astraeus	0	1	0	1	0	1	1	1	1	1	1	1	0	0	1	0	1	1
Bovista	1	2	0	0	1	1	1	1	0	1	1	3	1	1	1	1	0	3
Calvatia	1	0	0	1	0	1	3	2	1	2	2	2	2	1	1	0	0	3
Clathrus	0	0	0	0	0	0	0	1	0	0	1	1	1	0	1	0	0	1
Crucibulum	1	1	1	0	0	1	0	1	1	0	0	1	1	0	1	1	1	1
Cyathus	1	0	1	1	0	1	1	1	0	0	1	0	1	0	1	0	0	1
Geastrum	1	2	2	4	2	7	2	2	2	0	0	0	1	0	1	1	1	9
Lycoperdon	0	2	2	0	3	2	4	5	1	1	5	4	4	3	2	0	0	7
Melanogaster	0	1	1	2	0	2	1	0	0	1	1	0	0	0	0	0	0	2
Mutinus	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Myriostoma	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1
Pisolithus	0	0	0	1	0	1	1	0	1	0	1	0	0	1	0	0	0	1

	Q. ilex										*Q. suber*							**Total**
	AH-i	**GU-i**	**SH-i**	**JA-i**	**MA-i**	**CO-i**	**A-i**	**CM-i**	**JM-i**	**S-i**	**A-s**	**AI-s**	**AII-s**	**CF-s**	**CM-s**	**JM-s**	**S-s**	**Taxa**
Scleroderma	0	1	0	1	0	2	2	3	3	0	3	2	3	1	2	1	1	4
Sphaerobolus	1	1	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1
Vascellum	0	0	0	1	1	0	1	1	1	1	1	1	1	0	1	0	1	1
RUSSULALES	3	0	2	7	3	13	22	30	10	4	49	49	29	5	25	11	10	82
Lactarius	3	0	1	3	3	6	11	11	2	3	16	12	7	4	8	2	5	22
Russula	0	0	1	4	0	7	11	19	8	1	33	37	22	1	17	9	5	60