



# Exploring the biodiversity of key groups in coppice forests (Central Italy): the relationship among vascular plants, epiphytic lichens, and wood-decaying fungi

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## ABSTRACT

Sustainable Forest Management (SFM) indicators consider the main ecological and socioeconomic functions of forests but do not currently include some key groups widely adopted to assess the effects of forest management, such as herbaceous vascular plants, epiphytic lichens, and wood-decay fungi. Moreover, they are shaped into high forests while in the Mediterranean area the oldest type of forest management is coppice. We investigated the diversity and the relationships of the above-mentioned groups of taxa in three European Forest Types (EFTs) to contribute to the selection of indicator species suitable for monitoring Mediterranean coppice forests. We find only a weak cross-taxon congruence between vascular plants and lichens on considering the whole dataset, while no significant correlations are evident within the three EFTs. Species richness was significantly different among EFTs, being Thermophilous deciduous forests the richest, both considering the groups of taxa separately and the total species richness. As for species composition, significant differences were found both for the whole dataset and also for pairwise comparisons among EFTs. We provided a dwelling-species list of the three key groups of taxa, which could be suitable for monitoring the sustainability characteristics of fragmented and low continuity forests such as coppice stands.

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## Highlights

Vascular plants, epiphytic lichens and wood-decay fungi relationship in coppice stands

- Weak cross-taxon congruence between vascular plants and lichens
- Significant differences in species richness and composition among forest types
- We provide a list of dwelling-species suitable for monitoring coppices

## 1. Introduction

Forest Europe (2020), in the context of sustainable forest policy and governance at a Pan-European level, has developed several Sustainable Forest Management (SFM) indicators. Although they take into account the main ecological and socioeconomic functions of forests, including six SFM Criteria, the current setting shows at least two main shortcomings.

Firstly, these SFM consolidated indicators are mainly shaped for high forests (Forest Europe 2020). However, in the Mediterranean area, the oldest type of forest management is represented by coppice (Rackham 2008). Coppice forests cover about 10% (23 million ha) of European forest

areas (FAO (Food and Agriculture Organization of the United Nations) 2010). They are characterized by selective cutting rotations ranging from 15–20 years up to 50–60 years (Urbietta et al. 2008). This practice supported the socioeconomic structure of local communities for centuries, providing firewood and charcoal, mushrooms, honey, cork, fodder, fruits, pharmaceutical, and aromatic plants and representing a favourable environment for livestock grazing and hunting (Unrau et al. 2018). For this reason, there is still a significant lack of knowledge on this topic and a strong interest in finding key indicators useful also for coppice forests (Giordani 2012).

Secondly, SFM Criterion 4 indicators, dealing with biological diversity in forest ecosystems, do not currently include some key groups widely adopted to assess the effects of forest management, such as herbaceous vascular plants, epiphytic lichens and wood-decay fungi. These gaps are particularly important in considering the roles played by them in forests and their ecological relevance. Indeed, vascular plants provide physical structure for other organisms, include a large number of habitat specialists distributed across broad environmental gradients and are very well known by the taxonomic point of view. For these reasons they are traditionally considered one of the key surrogate groups to select areas of concern in biodiversity conservation since they can

reflect the diversity of other important and less easily detectable taxa (Pharo et al. 2000; Wolters et al. 2006; Santi et al. 2010; Bagella 2014; Burrascano et al. 2018).

Epiphytic lichens are among the most suitable indicators of forest management (see e.g. Rose 1992; Aragón et al. 2010; Giordani 2012; Nascimbene et al. 2013) and continuity (see e.g. Rose 1976; Nilsson et al. 1995; Brunialti et al. 2015), since forest structure and dynamics directly or indirectly affect the dispersal, establishment, and maintenance of lichen species (Hauck et al. 2013).

Wood-decay fungi play a crucial role in forest ecosystems since they are the principal decomposers of the wood (White 2003) with a selective action on the weaker trees (Hainaut Développement 2004; Blaser et al. 2013; Tomao et al. 2020). Besides, as they can also become a threat, monitoring them is relevant not only for biodiversity and ecological assessment but also for planning defence interventions (Hainaut Développement 2004).

Thermophilous Deciduous Forests (TDF), Mountainous Beech Forests (MBF), and Broadleaved Evergreen Forests (BEF) are among the main European Forest Types (EFT) in the Mediterranean area (Barbati et al. 2014) and most of their forest cover is traditionally managed as coppice in Italy (Mairota et al. 2018). Several studies explored the cross-congruence among different groups of taxa in these EFTs in the Mediterranean area (e.g. TDF: Landi et al. 2015; Brunialti et al. 2010; MBF: Blasi et al. 2010; Sabatini et al. 2016; and BEF: Chiarucci et al. 2005; see also Gao et al. 2015 for a review). However, most of these studies focused on high and/or old-growth forests while, as far as we know, a general information on the relationships among different taxa in coppice forests is still poorly explored.

To contribute to this topic, we studied the diversity and the relationships among vascular plants, epiphytic lichens and wood-decay fungi in coppice forest stands of the above-mentioned EFTs in Italy. In particular, we aim (i) to deepen the correlation among them in terms of species richness and composition and (ii) to select a list of species for each EFT that will be useful as indicators of future changes in the context of Mediterranean coppice stands.

## 2. Materials and methods

### 2.1. Study area and sampling design

The study was carried out in three forest districts located in the two Italian administrative regions of Tuscany and Sardinia (see map in Brunialti et al. 2020). A total of eighteen 20×40 m

permanent plots, belonging to a long-term forest monitoring network (Cutini et al. 2015; Chianucci et al. 2016), was considered. Field sampling was carried out from April to October 2016.

The three Forest Districts represent three European Forest Types (EFT) respectively, with the characteristics reported in Table 1:

- Thermophilous Deciduous Forests (TDF), 4 plots dominated by Turkey oak (*Quercus cerris* L.): Poggio Pievano, Colline Metallifere Forest District, Tuscany (43.11° N; 10.90° E).
- Mountainous Beech Forests (MBF), 5 plots dominated by European beech (*Fagus sylvatica* L.): Buca Zamponi, Alpe di Catenai Forest District, Tuscany (43.64° N; 11.92° E).
- Broadleaved Evergreen Forests (BEF), 9 plots dominated by holm oak (*Quercus ilex* L.): Is Cannoneris Forest District, Sardinia (39.06° N; 8.89° E).

From the structural point of view, beech stands (MBF) showed the lowest values of tree stems ( $p < 0.05$ ) and the highest values of tree height and volume ( $p < 0.01$ ) compared to the other two forest types (Table 1).

The presence of each species of vascular plants and wood-decaying fungi was recorded within one 10×10 m sub-plot, that was randomly selected within each plot. Fungi were sampled with two surveys in spring and autumn on all the trees, shrubs, stumps and deadwood substrates of each sub-plot.

For each 20×40 m plot, the diversity of epiphytic lichens was assessed on 4 randomly selected standard trees (DBH  $\geq$  16 cm, bole inclination  $< 30^\circ$ ), belonging to the dominant tree species (*F. sylvatica*, *Q. cerris*, and *Q. ilex*). In compliance with the standards described by Asta et al. (2002), EN 16413 (2014) and Stofer et al. (2016), the occurrence of each lichen species was sampled within a 10 cm × 50 cm observation grid, placed at each of the four cardinal points of the trunk (N, S, E, W) at a height of 100 cm above the ground.

Functional traits follow the European Nature Information System (EUNIS, <https://eunis.eea.europa.eu/species.jsp>) and nomenclature follows Bartolucci et al. (2018) and Galasso et al. (2018) for plants, Nimis and Martellos (2017) for lichens, and Bernicchia (2005), Bernicchia and Gorjòn (2010), and Ryvarden and Melo (2014) for fungi.

### 2.2. Data analysis

The software R was used for all statistical analyses (RStudio Team 2016).

**Table 1.** Descriptive statistics (median, min-max range) of the structural attributes of the sampled plots in the three EFTs.

Variables	European forest type			K-W ANOVA (df: 2; N: 18)
	BEF	MBF	TDF	
Tree stems (n ha <sup>-1</sup> )	850 (475–4063) <sup>a</sup>	413 (313–1900) <sup>b</sup>	3288 (775–5575) <sup>a</sup>	H: 7.2; $p < 0.05$
Basal area (m <sup>3</sup> ha <sup>-1</sup> )	24 (21.7–55.1) <sup>a</sup>	35.1 (26.7–48.1) <sup>a</sup>	26.6 (22.3–33.2) <sup>a</sup>	H: 2.8; n.s.
Mean tree height (m)	12.5 (10.1–14.3) <sup>a</sup>	23.9 (19.9–27.1) <sup>b</sup>	11.8 (9.2–19.2) <sup>a</sup>	H: 10.3; $p < 0.01$
Tree volume (m <sup>3</sup> ha <sup>-1</sup> )	171 (144–346) <sup>a</sup>	452 (322–545) <sup>b</sup>	185 (109–295) <sup>a</sup>	H: 9.9; $p < 0.01$

BEF: Broadleaved evergreen forests (9 plots), MBF: Mountainous Beech Forests (5 plots), TDF: Thermophilous deciduous forests (4 plots).

<sup>abc</sup>Same letters correspond to homogeneous groups ( $p > 0.05$ ) according to Wilcoxon test.

Species richness—Differences in species richness (alpha diversity) of the three groups of taxa (plants, lichens and fungi) among EFT were tested using one-way non-parametric Kruskal Wallis ANOVA (Kruskal and Wallis 1952). This is an alternative non-parametric one-way ANOVA, which is based on the differences between ranks instead that between the averages.

The Spearman rho rank correlation coefficient was used, with presence-absence data, to test if the species richness of the three groups of taxa was correlated. *p*-values were adjusted by the Bonferroni test. The correlations have been tested for the whole dataset and each EFT separately.

Species composition—Compositional differences of three groups of taxa (plants, lichens and fungi, 210 species) among EFTs were tested by multi-response permutation procedures (MRPP) using the Euclidean distance measure and rank transformation of the distance matrices. MRPP was used to test the pairwise differences between forest types as well as for the total, i.e. all the EFTs pooled together. The separation between groups was calculated as the chance-corrected within-group agreement (*A*) and the *p*-value was used for evaluating how likely an observed difference was due to chance (*A*=1 indicates perfectly homogenous groups, while *A*=0 indicates within-group heterogeneity equal to that expected by chance). In community ecology, values for *A* are commonly below 0.1, even when the observed data differ significantly from the expected (McCune and Grace 2002).

To assess the relationship among species occurrences and sampled plots a cluster analysis was performed, using Euclidean distance as clustering algorithm and complete linkage as similarity measure. To reduce noise from rare species, those occurring <20% of the plots were excluded (151 species).

The pattern of species composition was visually evaluated by non-metric multidimensional scaling (NMDS; McCune and Grace 2002) using the Bray Curtis distance measure. This iterative ordination method is based on ranked distances between sample units in the data matrix. It does not assume normally distributed data and is therefore suited for most ecological data. A final 3-dimensions

solution was selected (final stress: 0.045). The two most explicative axes were used for representing the spatial ordination of the data. A PERMANOVA (999 permutations), as well as an analysis of variance, were carried out to test the significant differences among EFTs and homogeneity of variance within each group, respectively. To reduce noise from rare species, those occurring <10% of the plots were excluded (86 species).

### 3. Results

#### 3.1. Species richness

A total of 210 species of plants (109), lichens (45) and fungi (59) was found in the 18 plots (Table 2; Appendix).

Correlations of the species richness among the taxonomic groups were statistically not significant for most comparisons (Table 2). In particular, the species richness of vascular plants was positively correlated to that of epiphytic lichens ( $R=0.56$ ,  $p<0.05$ ), but only considering the total dataset. The highest correlation between these two groups was found in TDF ( $R=0.95$ ), although with a not significant *p*-value when adjusted with the Bonferroni test ( $p=0.15$ ).

The mean number of species at plot level (alpha diversity) was variable across the three groups of taxa: 17.4 for plants, 10.9 for lichens and 6.8 for fungi (Table 3). Species richness was significantly different among EFTs ( $p<0.05$ ), both considering the groups of taxa separately and the total species richness. The results of the pairwise comparison showed that plant richness was significantly different among the three forest types (Wilcoxon test,  $p<0.05$ ), with the highest values for TDF (36) and the lowest for MBF (6). Lichen richness was significantly higher in TDF (17.8), while MBF and BEF showed similar values. BEF hosted a significantly lower number of wood-decaying fungi (3.6) compared to the other two EFTs. On considering the total species richness, TDF showed the highest number of species (63.3;  $p<0.05$ ), three times higher than the other EFT.

**Table 2.** Spearman rank correlation coefficient (Spearman rho) among the species richness of all taxonomic groups.

	European forest type							
	Total dataset		BEF		MBF		TDF	
	Fungi	Lichens	Fungi	Lichens	Fungi	Lichens	Fungi	Lichens
Plants	-0.06	0.56*	0.18	0.28	-0.26	0.38	0.20	0.95
Lichens	0.30	-	-0.15	-	0.08	-	0.32	-

*p*-values have been adjusted with the Bonferroni test ( $*p<0.05$ ).

**Table 3.** Descriptive statistics of the species richness (alfa diversity) of the three groups of taxa in the EFTs.

	Total		European forest type			K-W ANOVA (df: 2; N: 18)
	Study area	Plot level	BEF	MBF	TDF	
Plant species richness ( <i>n</i> )	106	17.4 ± 12.8	15.4 ± 8.5 <sup>b</sup>	6.0 ± 5.1 <sup>a</sup>	36.0 ± 2.2 <sup>c</sup>	H: 12.2; $p<0.01$
Lichen species richness ( <i>n</i> )	45	10.9 ± 5.2	8.4 ± 5.1 <sup>a</sup>	9.8 ± 0.8 <sup>a</sup>	17.8 ± 1.9 <sup>b</sup>	H: 8.4; $p<0.05$
Wood-decaying fungi species richness ( <i>n</i> )	59	6.8 ± 4.1	3.6 ± 1.9 <sup>a</sup>	10.6 ± 3.2 <sup>b</sup>	9.5 ± 2.9 <sup>b</sup>	H: 11.9; $p<0.01$
Total species richness (plants, lichens and fungi) ( <i>n</i> )	210	35.1 ± 17.8	27.4 ± 11.5 <sup>a</sup>	26.4 ± 6.0 <sup>a</sup>	63.3 ± 6.2 <sup>b</sup>	H: 8.86; $p<0.05$

Mean ± SD values are reported. Significant differences in species diversity among EFT were also tested using the Kruskal Wallis ANOVA test, and pairwise comparison between groups (Wilcoxon test). BEF: Broadleaved evergreen forests, MBF: Mountainous Beech Forests, TDF: Thermophilous deciduous forests.

<sup>abc</sup>Same letters correspond to homogeneous groups ( $p>0.05$ ) according to Wilcoxon test.

**Table 4.** A-statistics (chance-corrected within-group agreement) after MRPP analysis, applied to the whole dataset (all forest types), as well as for the pairwise comparisons among the three EFTs.

	A-statistics	p-value
All forest types	0.175	$p < 0.001$
BEF vs. MBF	0.106	$p < 0.01$
BEF vs. TDF	0.155	$p < 0.01$
MBF vs. TDF	0.164	$p < 0.05$

BEF: Broadleaved evergreen forests, MBF: Mountainous Beech Forests, TDF: Thermophilous deciduous forests. The  $p$ -value is the significance of the pairwise delta value for differences between groups.

### 3.2. Species composition

We used MRPP to evaluate the most significant differences in species composition (plants, lichens and fungi dataset) between forest types (Table 4). The higher the A value (chance-corrected within-group agreement), the stronger the between-group difference ( $p < 0.05$ ). Significant differences were found both for the whole dataset ( $p < 0.001$ ;  $A = 0.175$ ) and also for pairwise comparisons among EFTs, always with A-values  $> 0.1$ .

On considering that in community ecology, values for A are commonly below 0.1, even when the observed data differ significantly from the expected (McCune and Grace 2002), our results (A-statistics always  $> 0.1$ ) indicated that species assemblages do not overlap between forest types.

The cluster analysis clearly distinguished two clusters of species (Fig. 1): (i) cluster A included 28 species showing the highest occurrence in correspondence with the nine BEF plots (cluster 1). This cluster was mainly characterized by vascular plants (18 species, 64%), followed by lichens (7) and fungi (3). (ii) cluster B included 31 species that were linked to cluster 2, including both TDF and MBF plots (12 plants, 13 lichens and 6 fungi).

The visual interpretation of the NMDS ordination (Fig. 2) corroborated these results. The species composition among EFT was significantly different (PERMANOVA  $R^2$ : 0.591,  $p < 0.001$ ). The plots belonging to BEF and MBF were clearly separated along Axis 1. Thirty-four species (27% of the total) were significantly associated with BEF, mostly represented by vascular plants (23 species). On the opposite trend, only 18 species (3 plants, 4 lichens and 11 wood-decaying fungi) were strictly associated with MBF. These plots showed also the highest values of tree heights and volume. TDF plots were distributed to positive values of Axis 2, and they were clearly distinguished from the other two forest types in relation to a decreasing gradient in tree basal area. A group of 39 species (31% of the total), mainly represented by vascular plants (31 species), were associated with these plots.

The three EFTs showed different levels of variance within their plots ( $F$ : 4.142,  $p < 0.05$ ), denoting the widest range of variability in species assemblages for BEF, followed by MBF and TDF, thus confirming the results of the cluster analysis.

## 4. Discussion

The number of species of the three groups of taxa is rather low when compared to other studies (see e.g. Brunialti et al. 2010; Sabatini et al. 2016; Ujházy et al. 2018). This is probably due to the lower number of plots that we surveyed but also to the effect of coppice management related to habitat

fragmentation, alteration of microclimatic conditions, and, mainly for lichens and fungi, the reduced suitability of colonizing substrates (Murcia 1995; Fahrig 2003).

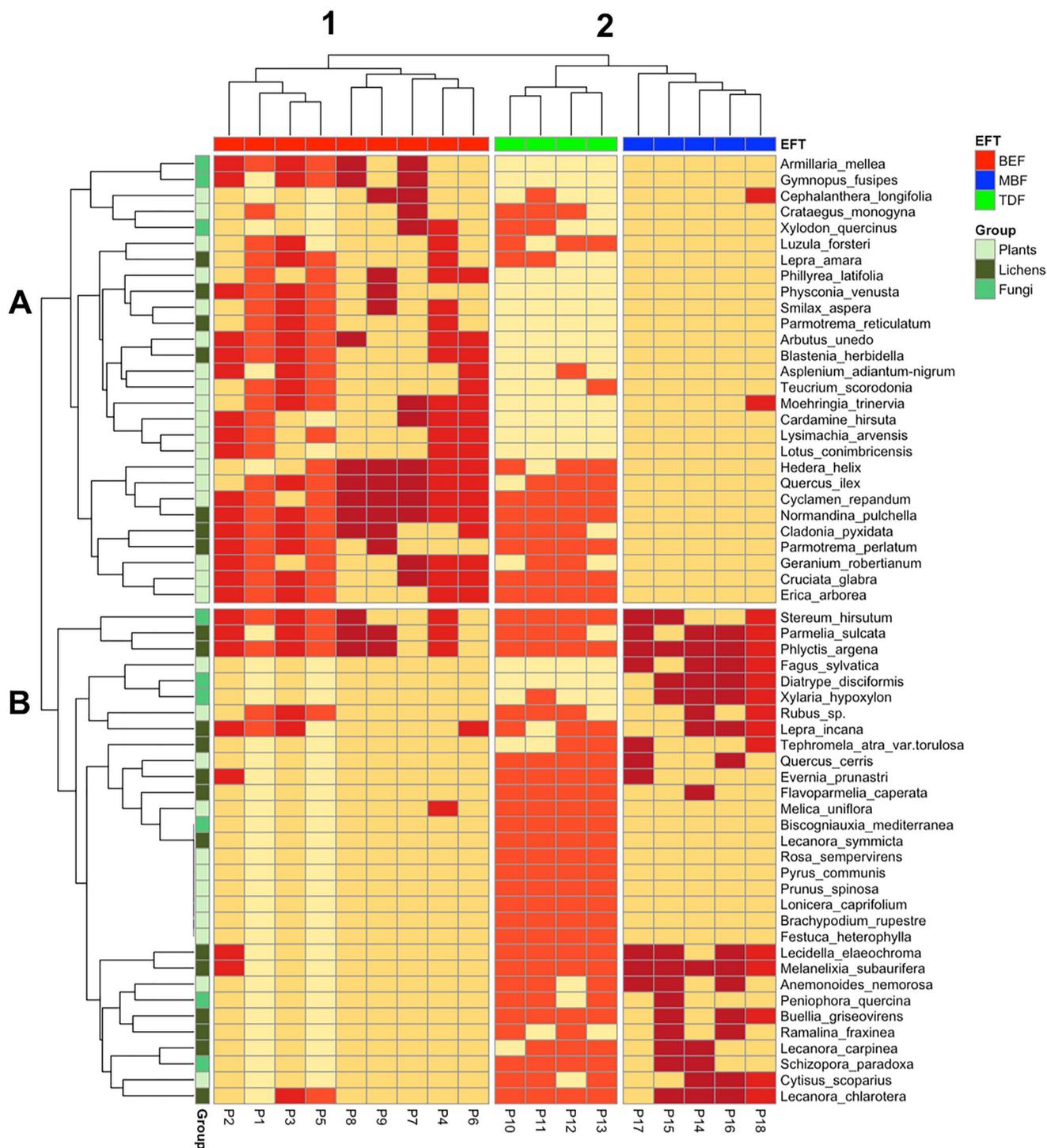
The identification of key taxonomic groups and the possible relationships among them can help conservation biologists to design simplified, standardized, and effective tools for biodiversity monitoring and to simplify and reduce the economic costs for monitoring the effects of forest management (Larrieu et al. 2018).

The relationships between taxonomic groups in forests were largely explored at different spatial scales and in different geographic areas (Blasi et al. 2010; Paillet et al. 2010; Bagella et al. 2014; Gao et al. 2015; Santi et al. 2016; Jokela et al. 2018). In general, a good level of cross-taxon congruence was observed at wide scales, usually, biogeographical ones (see e.g. Reid 1998; Myers et al. 2000; Westgate et al. 2014), and the choice of grain size, taxon, and type of predictor variables were identified to strongly influence the outcome of inferred patterns of biodiversity (Santi et al. 2016). When the spatial scale is broad, high environmental variability is usually considered, and the diversity patterns of different groups of species are more likely to co-vary, probably due to the common biogeographical and evolutionary history shared by these taxa (Gioria et al. 2011; Rooney and Azeria 2015).

In this study, we find only a weak cross-taxon congruence between vascular plants and lichens considering the whole dataset, while no significant correlations are evident within the three EFTs. The fine spatial scale (small grain) adopted may have driven our findings, as previously suggested by Sabatini et al. (2016) in a study carried out in several beech forests of the Italian Apennines.

The positive correlation between vascular plants and lichens is in agreement with the literature in this field. Indeed, several authors found that vascular plant species richness was positively correlated with species richness of bryophytes, lichens and fungi (Saetersdal et al. 2004; Sauberer et al. 2004; Dynesius and Zinko 2006; Blasi et al. 2010; Sabatini et al. 2016), and animal groups such as butterflies, collembola and birds (Hawkins and Porter 2003; Qian 2007; Santi et al. 2010; Rossetti et al. 2015). This confirms the fundamental role of vascular plants as key components for the structuring and functioning of terrestrial ecosystems (Pharo et al. 2000). In contrast with these studies, Ujházy et al. (2018), in a study carried out in beech forests of the Western Carpathians, found no correlation between number of species of plants and macrofungi. Similarly, we haven't found any correlation between wood-decaying fungi and the other two groups. This is probably because we considered only wood-inhabiting fungi, while many studies in literature sampled also epigeous and/or mycorrhizal ones. Another possible explanation for these results is the low number of plots examined and that we conducted a single year survey.

In this study, we explored the three main forest types managed as coppice in the Mediterranean area. *Fagus sylvatica*- and *Quercus ilex*-dominated forests represent respectively the typical Mediterranean montane and evergreen vegetation. *Quercus cerris* forests are an intermediate habitat being deciduous and thermophilous (Barbati et al. 2014).



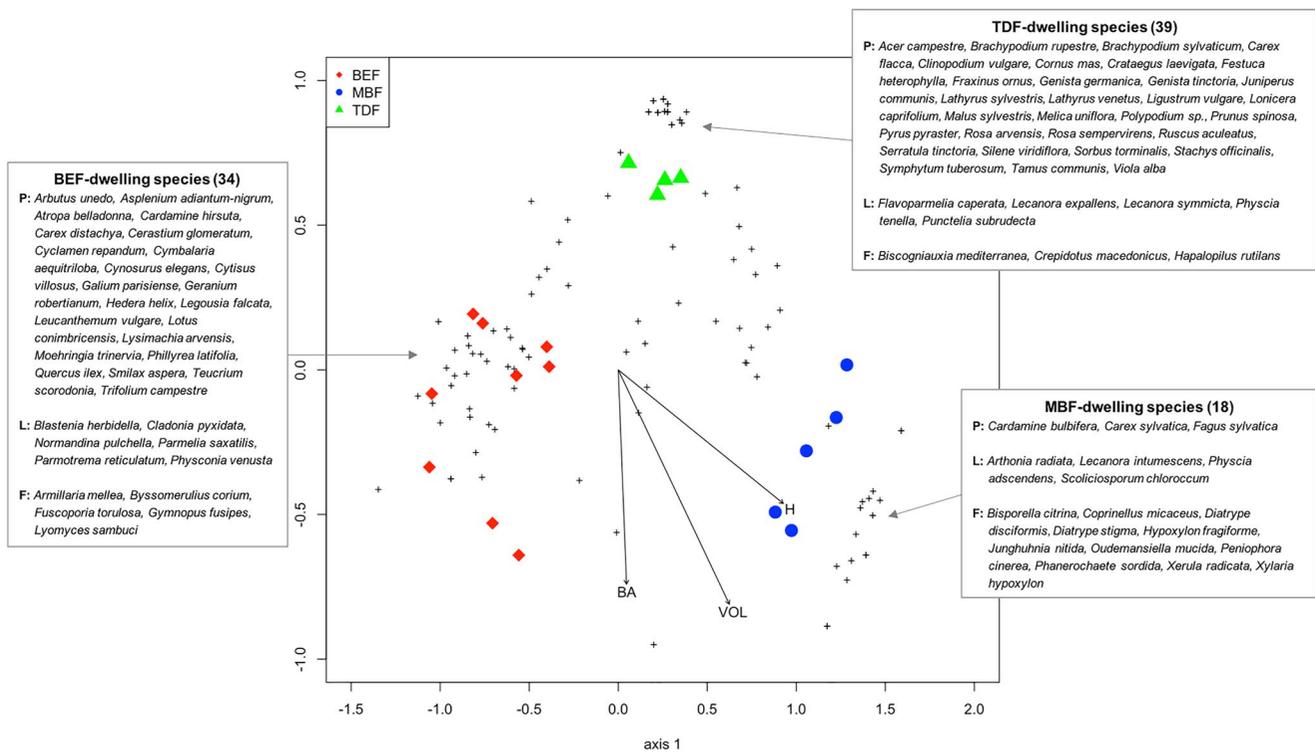
**Figure 1.** Heatmap cluster analysis diagram showing the distribution of the three groups of taxa (59 species) in the sampled plots (18). The colours from light yellow to dark red indicate the low to high correlations of the species with the plots.

Although our results can be affected by a potential covariance effect due to the clustered distribution of our plots, with a partial overlapping of forest site and forest category, forest types seem to play a pivotal role in influencing the species richness and composition of key groups of taxa.

Solar radiation and humidity under the canopy are probably the main environmental factors explaining these results. Indeed, light availability is one of the main determinants of the growth of plant species in forest understory (Elemans 2004; Van Calster et al. 2008) and it is different in deciduous

than in broadleaved evergreen forests, having also an effect on moisture. In our study, evergreen *Quercus ilex*-dominated forests are characterized by the lowest number of wood-decaying fungi and are separated from the other two EFTs in terms of species assemblages, denoting peculiar shade-adapted communities of plants and lichens.

As for deciduous forests, mountainous beech stands usually show a higher tree height and form dense canopies with very low light levels on the forest floor. Further, they are generally characterised by lower mean temperatures if



**Figure 2.** NMDS ordination (124 species  $\times$  18 plots). The species are represented by + symbols. BEF: Broadleaved evergreen forests, MBF: Mountainous Beech Forests, TDF: Thermophilous deciduous forests. BA: basal area, VOL: volume, H: height. Tables report the species that were found highly correlated with each EFT, split up into plants (P), lichens (L) and fungi (F).

compared to the other two EFTs. This reflects on lower vascular plant diversity due to the shorter growing-season period (Brown and Lomolino 1998). We find that our coppice *Fagus*-dominated plots show very few herbaceous indicator species but the highest number of fungi, which are strictly linked to these forest stands. The combination of the low light availability, the high understory humidity, and a higher substrate affinity can explain this favourable effect on saproxylic fungi communities (Granito et al. 2015; Persiani et al. 2016). This is in agreement with Sabatini et al. (2016) who found that higher levels of herb-layer species richness were associated with species-poor saproxylic fungi communities and vice versa.

On the contrary, *Quercus cerris*-dominated forests host the highest number of vascular plants and lichens, but they show an intermediate species composition when compared to the other two EFTs, with several species in common with them.

The highest plant richness in TDF can be ascribed to ecological factors (intermediate altitude and climate) and forest management based on frequent coppicing (Wright et al. 1993) which ensure an open canopy cover and, consequently, high solar radiation. This supports, as already observed, the presence of a high number of species in the understory layers (shrub and herb) in contrast with the low number of tree species (Chiarucci et al. 2001).

The highest values of lichen diversity are in agreement with the results of several studies on the Mediterranean fragmented oak forests (Belinchón et al. 2007; Brunialti et al. 2013a). Indeed, the gradual increase in forest fragmentation due to coppice management may alter the optimal habitat for shade-adapted species, favouring a set of heliophilous

and xerophilous species with a broad tolerance and an opportunistic strategy (Belinchón et al. 2007; Brunialti et al. 2013a). The result is a mixed assemblage made of both forest-dwelling species and species typical of isolated trees, greatly contributing to the diversity peak.

In our study, we focused on selecting forest dwelling-species lists of key groups of taxa for each of the three main Mediterranean EFTs managed as coppice. This approach is usually adopted for the conservation of rare or red-listed species that are significantly confined to mature or old-growth forest stands. For instance, in a study carried out on wood-inhabiting fungi in conifer Hemi-boreal forests, Runnel and Löhmus (2017), argue that expert lists of 'old-forest (indicator) fungi' should be replaced with evidence-based focal taxa. Also for lichens, within the same project, (Löhmus and Löhmus 2019) identified lists of indicative species (focal lichens) for guiding sustainable forest management for three types of forests: old-growth protected forests, mature production stands with reduced rotations and functioning, and retention forests. A similar approach was adopted in old-growth beech and oak forests of the Mediterranean area, both for lichens and other groups of taxa, such as vascular plants, saproxylic fungi and beetles, and bryophytes (Blasi et al. 2010; Nascimbene et al. 2010; Brunialti et al. 2013b; Lelli et al. 2019).

Compared to the studies mentioned above, we are not necessarily focusing on conservation-relevant species but our objective is shifted on the selection of evidence-based lists of taxa able to characterize coppice forests and their changes in time. Although we are aware that this study cannot be considered exhaustive, the lists of species that we have

identified and their relationships can be suitable as a baseline to monitor the sustainability characteristics of fragmented and low continuity forests such as coppice stands. The relatively commonness of these species improves their applicability as evidence-based indicator species in medium to long term studies.

## 5. Conclusions

Herbaceous vascular plants, epiphytic lichens and wood-decaying fungi are widely adopted to assess the effect of forest management.

This study represents a first attempt to understand the relationships among these groups of taxa in the context of coppice forests that still remain poorly explored when compared to high or old-growth forests. To cope with this, we focused on the three EFTs representing the gradient of the variability of coppice forests in a typical Mediterranean area.

Although with some limitations, mainly due to the low number of plots and to the overlapping of forest site and forest category, with a potential covariant influence in the effects on biodiversity, our results can contribute to obtain an interesting general view on the cross congruence among taxa and to identify a list of species that can be suitable to monitor in time the changes in coppice forests.

We are aware that due to these constraints still remains a lot of work to do, and further research is still needed to clarify the complex interactions between these indicators in forests managed as coppice.

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## CRedit authorship contribution statement

Luisa Frati: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing—original draft.

Giorgio Brunialti: Conceptualization, Investigation, Methodology, Writing—original draft.

Sara Landi: Data curation, Investigation, Writing—review & editing.

Rossella Filigheddu: Investigation, Writing—review & editing.

Simonetta Bagella: Project administration, Supervision, Conceptualization, Writing—original draft, review & editing.

## Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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**Appendix: List of the species of plants (109), lichens (45) and fungi (59) found in the 18 plots**

	Species frequency, %		
	BEF	MBF	TDF
<b>Vascular plants</b>			
<i>Abies alba</i> Mill.	0	20	0
<i>Acer campestre</i> L.	0	0	75
<i>Acer monspessulanum</i> L. subsp. <i>monspessulanum</i>	0	0	25
<i>Agrimonia eupatoria</i> L. subsp. <i>eupatoria</i>	0	0	25
<i>Aira elegantissima</i> Schur subsp. <i>elegantissima</i>	11	0	0
<i>Ajuga reptans</i> L.	0	0	25
<i>Anemone nemorosa</i> (L.) Holub	0	60	75
<i>Anthemis arvensis</i> L. subsp. <i>arvensis</i>	11	0	0
<i>Aphanes</i> sp.	11	0	0
<i>Arbutus unedo</i> L.	78	0	0
<i>Asparagus acutifolius</i> L.	11	0	0
<i>Asplenium adiantum-nigrum</i> L. subsp. <i>adiantum-nigrum</i>	44	0	25
<i>Atropa bella-donna</i> L.	22	0	0
<i>Betonica officinalis</i> L.	0	0	75
<i>Brachypodium rupestre</i> (Host) Roem. & Schult.	0	0	100
<i>Brachypodium sylvaticum</i> (Huds.) P.Beauv. subsp. <i>sylvaticum</i>	0	0	50
<i>Cardamine bulbifera</i> (L.) Crantz	0	40	0
<i>Cardamine graeca</i> L.	0	20	0
<i>Cardamine hirsuta</i> L.	56	0	0
<i>Carex distachya</i> Desf.	33	0	0
<i>Carex flacca</i> Schreb.	0	0	75
<i>Carex sylvatica</i> Huds.	0	40	0
<i>Castanea sativa</i> Mill.	0	20	0
<i>Cephalanthera longifolia</i> (L.) Fritsch	22	20	25
<i>Cerastium glomeratum</i> Thuill.	33	0	0
<i>Cistus monspeliensis</i> L.	11	0	0
<i>Clinopodium vulgare</i> L.	0	0	75
<i>Conyza</i> sp.	11	0	0
<i>Cornus mas</i> L.	0	0	75
<i>Crataegus laevigata</i> (Poir.) DC.	0	0	75
<i>Crataegus monogyna</i> Jacq.	22	0	75
<i>Crocus</i> sp.	0	0	25
<i>Cruciata glabra</i> (L.) C.Bauhin ex Opiz	78	0	100
<i>Cyclamen repandum</i> Sm. subsp. <i>repandum</i>	89	0	100
<i>Cymbalaria aequitriloba</i> (Viv.) A.Chev. subsp. <i>aequitriloba</i>	33	0	0
<i>Cynosurus effusus</i> Link	33	0	0
<i>Cytisus scoparius</i> (L.) Link subsp. <i>scoparius</i>	0	60	75
<i>Cytisus villosus</i> Pourr.	22	0	0
<i>Dactylis glomerata</i> L.	0	0	25
<i>Daphne laureola</i> L.	0	0	25
<i>Digitalis lutea</i> L.	0	20	0
<i>Digitalis purpurea</i> L.	11	0	0
<i>Dioscorea communis</i> (L.) Caddick & Wilkin	0	0	50
<i>Epipactis helleborine</i> (L.) Crantz	11	0	0
<i>Erica arborea</i> L.	67	0	100
<i>Erica scoparia</i> L. subsp. <i>scoparia</i>	0	0	25
<i>Euonymus europaeus</i> L.	0	0	25
<i>Fagus sylvatica</i> L. subsp. <i>sylvatica</i>	0	80	0
<i>Festuca heterophylla</i> Lam.	0	0	100
<i>Fraxinus excelsior</i> L. subsp. <i>excelsior</i>	0	0	25
<i>Fraxinus ornus</i> L. subsp. <i>ornus</i>	0	0	75
<i>Galium parisiense</i> L.	22	0	0
<i>Galium scabrum</i> L.	11	0	0
<i>Genista germanica</i> L.	0	0	50
<i>Genista tinctoria</i> L.	0	0	50
<i>Geranium dissectum</i> L.	0	20	0
<i>Geranium purpureum</i> Vill.	11	0	0
<i>Geranium robertianum</i> L.	67	0	50
<i>Hedera helix</i> L. subsp. <i>helix</i>	67	0	75
<i>Helleborus foetidus</i> L. subsp. <i>foetidus</i>	0	20	0
<i>Hieracium murorum</i> L.	0	0	25
<i>Juniperus communis</i> L.	0	0	50
<i>Lathyrus sylvestris</i> L. subsp. <i>sylvestris</i>	0	0	75
<i>Lathyrus venetus</i> (Mill.) Wohlf.	0	0	75
<i>Legousia falcata</i> (Ten.) Fritsch	22	0	0
<i>Leucanthemum vulgare</i> (Vaill.) Lam. subsp. <i>vulgare</i>	22	0	0
<i>Ligustrum vulgare</i> L.	0	0	50
<i>Limodorum abortivum</i> (L.) Sw.	11	0	0

<i>Lonicera caprifolium</i> L.	0	0	100
<i>Lotus conimbricensis</i> Brot.	44	0	0
<i>Luzula forsteri</i> (Sm.) DC.	33	0	75
<i>Lysimachia arvensis</i> (L.) U.Manns & Anderb.	56	0	0
<i>Malus sylvestris</i> Mill.	0	0	50
<i>Melica uniflora</i> Retz.	11	0	100
<i>Moehringia trinervia</i> (L.) Clairv.	67	20	0
<i>Myosotis discolor</i> Pers. subsp. <i>discolor</i>	11	0	0
<i>Phillyrea latifolia</i> L.	56	0	0
<i>Polypodium</i> sp.	0	0	50
<i>Prunus avium</i> (L.) L.	0	20	0
<i>Prunus spinosa</i> L. subsp. <i>spinosa</i>	0	0	100
<i>Pteridium aquilinum</i> (L.) Kuhn subsp. <i>aquilinum</i>	11	20	0
<i>Pyrus communis</i> L. subsp. <i>pyraster</i> (L.) Ehrh.	0	0	100
<i>Quercus cerris</i> L.	0	40	100
<i>Quercus ilex</i> L. subsp. <i>ilex</i>	89	0	75
<i>Rosa arvensis</i> Huds.	0	0	50
<i>Rosa sempervirens</i> L.	0	0	100
<i>Rubia peregrina</i> L.	0	0	25
<i>Rubus</i> sp.	33	40	75
<i>Rubus ulmifolius</i> Schott	11	0	0
<i>Ruscus aculeatus</i> L.	0	0	75
<i>Serratula tinctoria</i> L. subsp. <i>tinctoria</i>	0	0	50
<i>Sherardia arvensis</i> L.	11	0	0
<i>Silene viridiflora</i> L.	0	0	50
<i>Smilax aspera</i> L.	56	0	0
<i>Sorbus domestica</i> L.	0	0	25
<i>Sorbus torminalis</i> (L.) Crantz	0	0	75
<i>Stellaria nemorum</i> L.	0	20	0
<i>Symphytum tuberosum</i> L. subsp. <i>angustifolium</i> (A.Kern.) Nyman	0	0	50
<i>Teucrium chamaedrys</i> L.	11	0	0
<i>Teucrium scorodonia</i> L.	44	0	25
<i>Trifolium campestre</i> Schreb.	33	0	0
<i>Trifolium</i> sp.	11	0	0
<i>Veronica officinalis</i> L.	0	20	0
<i>Vicia sepium</i> L.	0	0	25
<i>Viola alba</i> Besser	0	0	75
<i>Viola reichenbachiana</i> Jord. ex Boreau	0	0	25
<b>Epiphytic lichens</b>			
<i>Arthonia radiata</i> (Pers.) Ach.	0	40	0
<i>Bacidia rubella</i> (Hoffm.) A. Massal.	11	0	0
<i>Blastenia herbidella</i> (Hue) Servit	67	0	0
<i>Buellia griseovirens</i> (Sm.) Almb.	0	60	100
<i>Candelaria concolor</i> (Dicks.) Stein	0	0	25
<i>Candelariella reflexa</i> (Nyl.) Lettau	11	0	0
<i>Candelariella xanthostigma</i> (Ach.) Lettau	0	0	25
<i>Cladonia pyxidata</i> (L.) Hoffm.	78	0	75
<i>Coenogonium pineti</i> (Ach.) Lücking & Lumbsch	0	0	25
<i>Dendrographa decolorans</i> (Sm.) Ertz & Tehler	11	0	0
<i>Evernia prunastri</i> (L.) Ach.	11	20	100
<i>Flavoparmelia caperata</i> (L.) Hale	0	20	100
<i>Hyperphyscia adglutinata</i> (Flörke) H.Mayrhofer & Poelt	11	0	0
<i>Hypogymnia physodes</i> (L.) Nyl.	0	0	25
<i>Lecanora albella</i> (Pers.) Ach.	0	20	0
<i>Lecanora carpinea</i> (L.) Vain.	0	40	75
<i>Lecanora chlarotera</i> Nyl. subsp. <i>chlarotera</i>	22	80	100
<i>Lecanora expallens</i> Ach.	0	0	50
<i>Lecanora horiza</i> (Ach.) Linds.	11	0	0
<i>Lecanora intumescens</i> (Rebent.) Rabenh.	0	60	0
<i>Lecanora symmicta</i> (Ach.) Ach.	0	0	100
<i>Lecidella elaeochroma</i> (Ach.) M. Choisy var. <i>elaeochroma</i> f. <i>elaeochroma</i>	11	80	100
<i>Lepra amara</i> (Ach.) Hafellner	44	0	50
<i>Lepraria incana</i> (L.) Ach.	44	60	75
<i>Melanelixia subaurifera</i> (Nyl.) O. Blanco, A. Crespo, Divakar, Essl., D. Hawksw. and Lumbsch	11	100	100
<i>Naetrocymbe punctiformis</i> (Pers.) R.C. Harris	11	0	0
<i>Nephroma laevigatum</i> Ach.	11	0	0
<i>Normandina pulchella</i> (Borrer) Nyl.	100	0	100
<i>Parmelia saxatilis</i> (L.) Ach.	33	0	0
<i>Parmelia sulcata</i> Taylor	67	80	75
<i>Parmotrema perlatum</i> (Huds.) M.Choisy	56	0	100
<i>Parmotrema reticulatum</i> (Taylor) M.Choisy	44	0	0
<i>Pertusaria pertusa</i> (L.) Tuck. var. <i>pertusa</i>	0	20	0
<i>Pertusaria pustulata</i> (Ach.) Duby	11	0	50
<i>Phlyctis argena</i> (Spreng.) Flot.	78	100	100

<i>Physcia adscendens</i> H.Olivier	0	60	0
<i>Physcia tenella</i> (Scop.) DC.	0	0	50
<i>Physconia venusta</i> (Ach.) Poelt	56	0	0
<i>Pseudevernia furfuracea</i> (L.) Zopf var. <i>furfuracea</i>	11	0	0
<i>Punctelia subrudecta</i> (Nyl.) Krog	0	0	75
<i>Ramalina fraxinea</i> (L.) Ach.	0	40	50
<i>Ramalina</i> sp.	11	0	0
<i>Ricasolia amplissima</i> (Scop.) De Not.— <i>cyanomorph</i>	11	0	0
<i>Scolicosporum chlorococcum</i> (Stenh.) Vězda	0	60	0
<i>Tephromela atra</i> var. <i>torulosa</i> (Flot.) Hafellner	0	40	50
<b>Wood decay fungi</b>			
<i>Antrodia macra</i> (Sommerf.) Niemelä	0	20	0
<i>Antrodia</i> sp.	0	20	0
<i>Antrodiella romellii</i> (Donk) Niemelä	0	0	25
<i>Armillaria mellea</i> (Vahl) P. Kumm.	67	0	0
<i>Armillaria tabescens</i> (Scop.) Emel	0	0	25
<i>Auricularia auricula-judae</i> (Bull.) J. Schröt.	0	0	25
<i>Bertia moriformis</i> (Tode) De Not.	0	20	0
<i>Biscogniauxia mediterranea</i> (De Not.) Kuntze	0	0	100
<i>Bisporella citrina</i> (Batsch) Korf & S.E.	0	40	0
<i>Byssomerulius corium</i> (Pers.) Parmasto	33	0	0
<i>Ceriporiopsis gilvescens</i> (Bres.) Domanski	0	20	0
<i>Coprinellus micaceus</i> (Bull.) Vilgalys	0	40	0
<i>Coprinus alopecia</i> Lasch	0	0	25
<i>Crepidotus macedonicus</i> Pilát	0	0	50
<i>Cylindrobasidium laeve</i> (Pers.) Chamuris	0	20	0
<i>Daedaleopsis confragosa</i> (Bolton) J. Schröt.	0	20	0
<i>Daedaleopsis tricolor</i> (Bull.) Bondartsev & Singer	0	20	0
<i>Diatrype disciformis</i> (Hoffm.) Fr.	0	80	0
<i>Diatrype stigma</i> (Hoffm.) Fr.	0	40	0
<i>Fuscoptoria torulosa</i> (Pers.) T. Wagner & M. Fisch.	22	0	0
<i>Gloeocystidiellum clavuligerum</i> (Höhn. & Litsch.) Nakasone	0	20	0
<i>Gymnopus fusipes</i> (Bull.) Gray	56	0	0
<i>Hapalopilus rutilans</i> (Pers.) Murrill	0	0	50
<i>Hypholoma fasciculare</i> (Huds.) P. Kumm.	0	20	0
<i>Hypoxylon fragiforme</i> (Pers.) J. Kickx f.	0	60	0
<i>Inonotus cuticularis</i> (Bull.) P. Karst.	0	0	25
<i>Junghuhnia nitida</i> (Pers.) Ryvarden	0	40	0
<i>Laxitextum bicolor</i> (Pers.) Lentz	0	20	0
<i>Lentinellus micheneri</i> (Berk. & M.A. Curtis) Pegler	0	20	0
<i>Lyomyces sambuci</i> (Pers.) P. Karst.	22	0	0
<i>Mycena stipata</i> Maas Geest. & Schwöbel	0	20	0
<i>Mycena stylobates</i> (Pers.) P. Kumm.	0	20	0
<i>Oligoporus mappa</i> (Overh. & J. Lowe) Gilb. & Ryvarden	0	20	0
<i>Oudemansiella mucida</i> (Schrad.) Höhn.	0	40	0
<i>Peniophora cinerea</i> (Pers.) Cooke	0	40	0
<i>Peniophora quercina</i> (Pers.) Cooke	0	20	75
<i>Peniophorella praetermissa</i> (P. Karst.) K.H. Larss.	0	0	25
<i>Phanerochaete laevis</i> (Fr.) J. Erikss. & Ryvarden	0	20	0
<i>Phanerochaete sordida</i> (P. Karst.) J. Erikss. & Ryvarden	0	40	0
<i>Phanerochaete tuberculata</i> (P. Karst.) Parmasto	0	0	25
<i>Phellinus punctatus</i> (P. Karst.) Pilát	11	0	0
<i>Phlebia capitata</i> Bernicchia & Gorjón	11	0	0
<i>Phlebia rufa</i> (Pers.) M.P. Christ., Dansk	0	0	25
<i>Pleurotus cornucopiae</i> (Paulet) Rolland	0	0	25
<i>Polyporus tuberaster</i> (Jacq. ex Pers.) Fr.	0	0	25
<i>Polyporus varius</i> (Pers.) Fr.	0	20	25
<i>Scenidium nitidum</i> (Durieu & Mont.) Kuntze	11	20	25
<i>Schizopora paradoxa</i> (Schrad.) Donk	0	40	100
<i>Simocybe sumptuosa</i> (P.D. Orton) Singer	0	0	25
<i>Steccherinum ochraceum</i> (Pers. ex J.F. Gmel.) Gray	0	20	25
<i>Stereum hirsutum</i> (Willd.) Pers.	67	60	100
<i>Terana caerulea</i> (Schrad. ex Lam.) Kuntze	0	0	25
<i>Tremella mesenterica</i> Retz.	11	20	0
<i>Trichaptum bifforme</i> (Fr.) Ryvarden	11	0	25
<i>Xerula radicata</i> (Relhan) Dörfelt	0	40	0
<i>Xylaria hypoxylon</i> (L.) Grev.	0	80	25
<i>Xylodon juniperi</i> (Bourdot & Galzin) Hjortstam & Ryvarden	0	20	0
<i>Xylodon nespori</i> (Bres.) Hjortstam & Ryvarden	11	0	0
<i>Xylodon quercinus</i> (Pers.) Gray	22	0	50

Species frequency is expressed as the percentage of plots for each European Forest type in which the species occurred.

BEF: Broadleaved evergreen forests,  $n=9$  plots; MBF: Mountainous beech forests,  $n=5$  plots; TDF: Thermophilous deciduous forests,  $n=4$  plots.