

Forest stand structure and coarse woody debris determine the biodiversity of beetle communities in Mediterranean mountain beech forests



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ABSTRACT

The relationships between structural complexity, deadwood abundance, microhabitat type and species-diversity indicators are excellent tools to monitor biodiversity in forest ecosystems.

In spite of their importance, correlations between structural traits and Coleoptera communities in Mediterranean mountain forests have only rarely been investigated. Consequently, the magnitude and direction of the relationships between forest traits and biodiversity indicators remain poorly understood. In this study, we analyzed whether biodiversity indices of saproxylic and non-saproxylic beetle communities could be influenced by stand structure, microhabitat type, and deadwood abundance in two protected beech forests located in the central and southern Apennines (namely Gran Sasso e Monti della Laga National Park, GSML, and Cilento, Vallo di Diano e Alburni National Park, CVDA). Standard measurements of forest structural traits and quantitative assessment of tree microhabitats and deadwood were carried out. Adult beetles were collected using window flight traps and emergence traps on decaying deadwood. The two beech forests were different in terms of both beetle communities and structural traits. A two-block partial least squares analysis 2B-PLS highlighted differences in biodiversity indices and structural traits between the two forest ecosystems. In GSML, we observed that biodiversity indices were positively correlated with the volume of coarse woody debris and the presence fungal infections, clefts into the sapwood, and woodpecker cavities, while more dominant beetle communities were found under denser canopy cover. In CVDA, Coleoptera abundance was positively correlated with the basal area and crown broken microhabitats. Our results point toward the relevance of ecological attributes in tracking changes in beetle biodiversity in specific forest contexts. In these protected Mediterranean mountain beech stands, in which the main forest management strategies have the primary objective of biodiversity conservation, we suggest to

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progressively increase the structural diversity and canopy dynamics, as well as the volume of coarse woody debris.

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1. Introduction

Forest biodiversity is currently under threat from climate and land-use changes, with negative impacts on adaptation and mitigation potentials (Hisano et al., 2018). Thus, the conservation of biological diversity is an important goal of sustainable forest management (Lindenmayer et al., 2000; Brunet et al., 2010), which represents a relevant factor influencing species richness and forest productivity. Accordingly, in relation to the applied measures, there can be either positive or negative effects on forest biodiversity (Kutnar et al., 2015), as different approaches to forest management could be applied for preserving ecological functions and providing ecosystem services. Insects are a key component in the provision, regulation and dynamics of many ecosystem services (Schowalter, 2013) and are involved in the four broad types of services defined by the Millennium Ecosystem Assessment (2003): (i) supply services; (ii) support services; (iii) regulatory services; and (iv) cultural services (Prather et al., 2013). There is a general lack of knowledge on the functional roles played by most species in nature (Hortal et al., 2015). Despite their enormous diversity, insects are often underrepresented in ecosystem studies, so their contribution to ecosystem functioning has been relatively less studied than other organisms such as plants (Schowalter, 2016). As a result, we often lack a complete understanding of the role of insects in many ecosystem processes that underlie ecosystem services (Boerema et al., 2017).

However, monitoring and testing the effectiveness of alternative management approaches to preserve forest biodiversity is challenging (Paillet et al., 2010). Determining status and tracking changes of forest biodiversity require the use of indicators, which help to measure and to monitor the threats to species occurrence and richness (e.g., saproxylic organisms), as well as the dynamics of stand and habitat structures (e.g., deadwood characteristics). Structural elements of forest stands are linked with habitat requirements of forest species (tree microhabitats) and can be used to assess the status of biodiversity in forest ecosystems (Michel and Winter, 2009; Winter and Möller, 2008; Ekström et al., 2021).

The loss of microhabitats is among the various factors that threaten biodiversity in forest ecosystems (Larrieu et al., 2018). These ecological niches include different structural characteristics of trees, which are habitats for several species, or guilds, to carry out their biological cycles, or exploit food resources (Winter and Möller, 2008). Usually, microhabitats are associated with a decrease in tree vitality caused by a combination of fungi, viruses, and bacteria (Larrieu and Cabanettes, 2012). However, microhabitats are useful in describing the level of forest naturalness, integrating structural complexity and diversity of deadwood (Michel and Winter, 2009).

Deadwood represents a typical structural key-component of forest ecosystems and species diversity (Müller and Bütler, 2010; Thorn et al., 2020a). Deadwood is a source of food for invertebrates (Siitonen, 2001) and a supporting substrate for bryophytes (Odor and Standovár, 2001) and lichens (Humphrey et al., 2002). It is pivotal in organic matter decomposition operated by a large community of bacteria and fungi (Sanderman and Amundson, 2003). The progression of deadwood decay provides nutrients and moisture that benefits many organisms (Bani et al., 2018; Parisi et al., 2018). In addition, a large variety of animals use deadwood substrates as a refuge, such as amphibians (Herbeck and Larsen, 1999) and small mammals (Williams-Guillén et al., 2016) or exploit it also for foraging, as in birds (Mikusinski and Angelstam, 1997; Innangi et al., 2019). Deadwood amount depends on numerous factors, including the intensity and type of silvicultural practices (Guby and Dobbertin, 1996). Managed stands are usually poor in deadwood amounts when compared to unmanaged forests (Paillet et al., 2015). However, deadwood amounts are also influenced by the frequency, intensity and type of natural disturbances (Thorn et al., 2020b).

In the mountainous areas of the northern Mediterranean basin, land-use abandonment led to the expansion of forest cover and the increase in the structural complexity of these forests. Nevertheless, deadwood amounts in these forest ecosystems, mainly dominated by *Fagus sylvatica* L. (beech), are still low, ranging between 5 and 40 m³ ha⁻¹, with percentages varying between 5% and 30% of the standing biomass (Forest Europe, 2015). By contrast, in some protected areas, where mature beech stands are dominant, the total amount of deadwood can even reach 150 m³ ha⁻¹ (Lombardi et al., 2012). Further investigations are needed to better understand the ecological relationships between the abundance and diversity of target species (e.g., saproxylic fauna) related to deadwood decomposition, the structural characteristics of the forest stand, and the habitat requirements of decomposers (Paillet et al., 2018).

The link between the complexity of forest stands and the abundance and diversity of saproxylic species has been recently highlighted in Mediterranean forests, confirming the effectiveness of the heterogeneity in these types of microhabitats for monitoring biodiversity (Parisi et al., 2020a; Pioli et al., 2018). It is also true that about 30% of the total biodiversity of a forest environment is linked to deadwood, reaching 50% in some taxonomic groups, such as beetles. In Europe, 4000 species of beetles are dependent on deadwood (Stokland et al., 2012) and they have a pivotal ecological role in assisting fungi and bacteria in the decomposition processes of organic matter and nutrient cycles (Parisi et al., 2018). However, many saproxylic organisms are under threat and the continuous availability of deadwood at a given site is essential for the survival of these species (Nieto and Alexander, 2010). Parisi et al. (2016) highlighted that the spatial distribution of deadwood with large diameters is particularly important for saproxylic species with limited dispersion capacities and with long biological cycles. The complex interactions in

the food network suggest that the loss of basic decomposers can influence the key processes of the whole forest ecosystem (Parisi et al., 2018).

Surveying sites of high conservation value rely on species lists (Rondinini and Chiozza, 2010). However, the assessment of the conservation value of forest areas based on species richness is challenging (Lachat et al., 2012), particularly for the complex communities of Mediterranean mountains. Beetles, especially saproxylic species, are considered promising indicators for assessing the proximity of European forests to near-natural conditions (Gossner et al., 2016; Lelli et al., 2019).

In this contribution we investigated the associations between the abundance and diversity of Coleoptera and the indicators of forest naturalness (i.e. stand structure, microhabitat type, and deadwood abundance) in mountain beech forests of two important national parks of Italy: Gran Sasso e Monti della Laga (GSML), and Cilento, Vallo di Diano e Alburni (CVDA). We expected that patterns of covariation could be found between beetle communities richer in species or higher in dominance and specific microhabitats. By evaluating patterns of abundance and richness of preferential microhabitats and cooccurring Coleoptera in unmanaged forests, we aimed at assessing whether and how the abundance and richness of specific microhabitats may influence the diversity of beetle communities, and if we might consider these relationships as ecological references in terms of biodiversity indicators in mountain beech forests. We believe that protected areas may help counteract species loss and habitat degradation, occurring in more-degraded Mediterranean environments.

2. Materials and methods

2.1. Study area

The study was conducted in two mountain areas located in the central and southern Apennines (Italy) (Fig. 1). The two sites are representative of montane beech and coniferous forests of the Mediterranean, Anatolian and Macaronesian regions (European Environment Agency, 2006), both located within the temperate bioclimatic region, humid-meso-temperate type.

The Gran Sasso e Monti della Laga National Park (GSML) covers approximately 149,000 ha in the central Apennines, between the Marche, Lazio and Abruzzo regions. Forests cover over 60% (about 87,000 ha) of the total protected area. The most widespread forest types are stands dominated by beech, sometimes with the occurrence of *Abies alba* Mill., *Ilex aquifolium* L. and *Taxus baccata* L. They extend mainly on the northern and eastern slopes of the Gran Sasso and the Monti della Laga mountains. Portions of old-growth forest also occur (Calamini et al., 2011).

The Cilento, Vallo di Diano e Alburni National Park (CVDA) is one of the largest protected areas in south-eastern Europe. It extends for over 181,000 ha, in the Campania region. It spreads from the Tyrrhenian sea level to 1899 m a.s.l. of the Cervati mountains, thus showing exceptional ecological interest due to its wide range of habitats and high levels of biodiversity (Marchetti et al., 2010). In fact, more than 1800 plant species are present, and the area is covered mainly by deciduous forests,

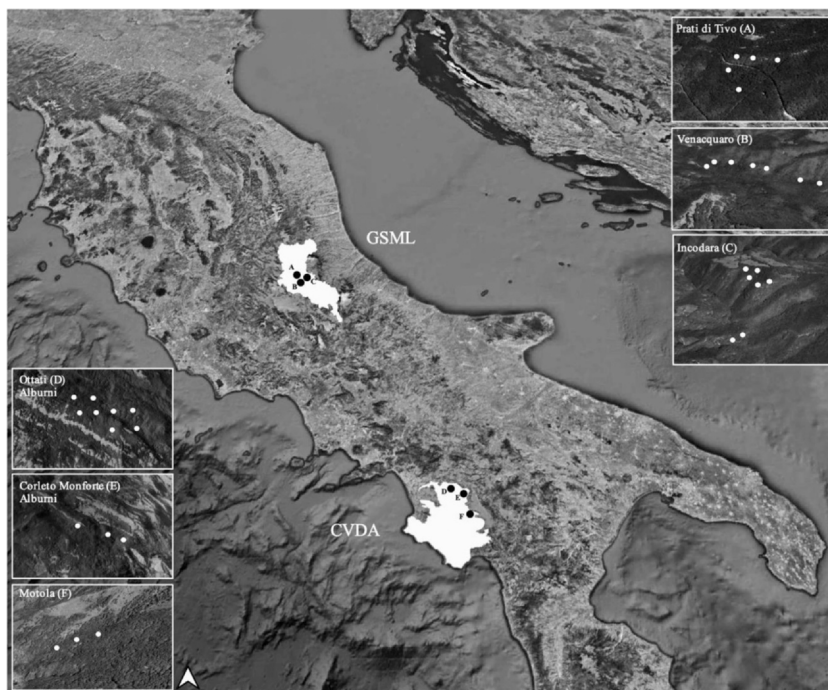


Fig. 1. The two national parks in central and southern Italy; black dots are the study sites selected in each park, while the white dots represent the location of the sampling plots realized for each investigated area.

Table 1
Main characteristics of the study areas (from Sabatini et al., 2016).

National Park	Municipality (study area)	Coordinates (degrees)	Elevation (m a.s.l.)	Mean Annual Precipitation (mm)	Mean Annual Temperature (°C)	Extension of the area (ha)	Number of sampling plots
GSML	Pietracamela (Prati di Tivo)	42.5096N 13.5679 E	1500	1062	10.6	7.86	5
	Pietracamela (Venacquaro)	42.4988N 13.5139 E	1250	1097	10.0	17.45	7
	Crognaleto (Incodara)	42.5123N 13.4735 E	1400	1097	10.0	11.23	7
	Corleto Monforte (Alburni)	40.4705N 15.4317 E	1300	1250	10.0	20.21	3
CVDA	Ottati (Alburni)	40.5136N 15.3292 E	1350	718	13.6	11.82	8
	Teggiano (Motola)	40.3761N 15.4694 E	1200	716	13.5	1.3	3

dominated by *Quercus cerris* L., *Q. pubescens* Willd., *Acer* sp. pl., *Ostrya carpinifolia* Scop., *Carpinus* sp. pl., *Fraxinus ornus* L. and *Castanea sativa* Mill. At higher elevations, over 1000 m a.s.l., beech forests are prevalent.

Two priority habitats of European interest according to the EU Habitats Directive (92/43/EEC) are in these areas: the habitat 9210* "Apennine beech forests with *Taxus* and *Ilex*" and the habitat 9220* "Apennine beech forests with *Abies alba* and beech forests with *Abies nebrodensis*". These beech forests are relatively species-rich both in the tree, in the shrub and herb layers. In each national park, three different beech forest stands were investigated (Table 1).

2.2. Living trees, deadwood and microhabitats survey

Three study sites were selected in each investigated national park, for a total of about 70 ha. We sampled 33 plots, 19 in GSML and 14 in CVDA (Table 1).

Two study sites located in the Cilento CVDA (i.e., 'Ottati' and 'Corleto Monforte'), belonging to the same Habitat type (habitat 9210*), were analysed together as "Alburni".

Each plot extended 530 m²; the sampling protocol followed Lombardi et al. (2015). In detail, UTM-WGS84 coordinates (Zone 32T) and elevation (m a.s.l.) were recorded in each plot using a Juno SB Global Positioning System (GPS) (Trimble, Sunnyvale, California). All living trees (minimum diameter at breast height ≥ 10 cm) were sampled, recording stem diameter at breast height (DBH), height, and species of each tree, and canopy cover. Deadwood was also surveyed. In detail, dead downed trees, snags, coarse woody debris (CWD) and stumps were sampled, measuring their length/height, minimum (≥ 5 cm) and maximum diameter and recording the species, when possible (Table 2).

The volume of living trees and standing and dead downed trees was calculated by double-entry volume equations (Tabacchi et al., 2011), while the volume of snags, CWD and stumps were calculated through the cone trunk formula (Lombardi et al., 2012). We also surveyed a set of 15 tree-related microhabitats that were present in the same sample plots (Table 3). These microhabitats are linked to the forest components on which they were found (living trees or deadwood components, e.g., dead branches, stem cavities, cracked and loose bark, fruiting bodies, crown substitute or secondary, mold pockets) and were classified according to Winter and Möller (2008).

2.3. Beetle trapping

In the same 33 plots where the structural characteristics of the forest were measured, the capture of both saproxylic and non-saproxylic adult beetles was carried out. Sampling of beetle fauna was carried out using two methods: window flight traps for flying beetles and emergence traps for beetles moving on the surface of dead trunks/branches or emerging from deadwood at different stages of decay. Traps were checked approximately every 30 days, for a total of four surveys in 2016 (from June to

Table 2
Tree variables used for the statistical analysis.

Variable	Unit of measurement	Acronym
Living trees volume	m ³ ha ⁻¹	VOL/ha
Basal area	m ² ha ⁻¹	G/ha
Canopy cover	%	Canopy
Coarse woody debris volume	m ³ ha ⁻¹	CWD
Volume of stumps	m ³ ha ⁻¹	Stumps

Table 3

Definition and description of the type of microhabitat used for statistical analysis following Winter and Möller (2008).

Microhabitat type	Definition
M1	Living trees with fruiting bodies of <i>Fomes fomentarius</i> (L. ex Fr.) Fr.
M2	Living trees with fruiting bodies of <i>Fomitopsis pinicola</i> (Swartz ex Fr.) Karst.
M3	Other fungal infections: living trees with fruiting bodies (for instance <i>Pleurotus ostreatus</i> (Jacq. ex Fr.) Kummer, obvious infections like <i>Inonotus obliquus</i> (Bolton: Fries) Pilát). Fruiting bodies were > 5 cm in diameter or occur in 10 cm long cascades of smaller fruiting bodies
M4	< 50% of the crown broken: significant loss of a part or parts of the crown. One or more main branches are lost. The remaining crown seems to be ≥50% of the former crown
M5	≥50% of the crown broken: several main branches are broken. The remaining crown seems to be < 50% of the former crown
M7	Broken stem: the crown is totally absent. Underneath the fracture, some very small living twigs have remained. This microhabitat type can develop into a substitute crown (M8)
M9	Lightning scar: a crack caused by lightning; at least 3 m long and reaching the sapwood
M10	Crack: cleft into the sapwood > 50 cm long along the stem and at least 2 cm deep in the sapwood
M12	Cavities with > 5 cm aperture: (A) entrance of a Black Woodpecker <i>Dryocopus martius</i> cavity, (B) entrance of a Green Woodpecker <i>Picus viridis</i> cavity and (C) entrance at hollowed branch forms cavity in stem
M16	Mould pockets: space between loose bark and the sapwood with a minimum extension of 5 cm × 5 cm × 2 cm
M18	Canker: proliferation of cell growth; irregular cellular growth on stems or branches, which is caused by bark inhabiting fungi, viruses and bacteria. The healing of the bark by wound callus (Grunwald et al., 2002) fails as the pathogen colonizes the callus tissue of the bark. We recorded areas of canker ≥10 cm in diameter
M19	Bark loss: patches with bark loss of at least 5 cm × 5 cm mainly caused by felling or natural falling of trees. At the stem base, bark losses are caused by moving logs. Bark losses are easily colonized by fungi and later by insects, which results in a loss of vitality of the whole tree within only a few years
M21	System of galleries on deadwood (Scolytid activities)
M22	Woody debris and/or stumps with saproxylic insect holes
M23	Water-filled rot hole on stumps

October). Emergence traps were emptied only once, at the end of the sampling period. All the monitoring systems were then removed during winter.

Systematics and nomenclature followed Bouchard et al. (2011) and Audisio et al. (2015). All the taxa collected during the field activities are alphabetically listed in Table A. Species strictly considered as saproxylic (*sensu*, Carpaneto et al., 2015) are also reported in Tables A, together with their risk category at the Italian level (see Audisio et al., 2015; Carpaneto et al., 2015).

2.4. Biodiversity and statistical analyses

Several diversity indices were computed, including the overall number of taxa (Taxa), the overall number of individuals (Individuals), Simpson's dominance index (Dominance), Shannon-Wiener entropy index (Shannon), Margalef richness index (Margalef), Pielou's evenness (Equitability), and Fisher's alpha diversity index. These indices are commonly used for investigating alpha diversity within biological communities (Harper, 1999). For a more synthetic description of the beetle community, the most representative 12 species among all sites were selected. We set a threshold of 2% for a Grand Weighted Mean (GWM) based on the percentage abundance of each taxon per sample (Ferraro et al., 2020). Given the total number of samples (33), a taxon *i*, the number of samples *j* where such taxon has at least one individual, the number of individuals *n* for each taxon and the overall number of individual N for each sample; then, the GWM was computed as follow:

$$GWM_i = \frac{\sum_j \left(\frac{n_{ij}}{N_j} \times 100 \right)}{33}$$

When needed, the overall statistical difference between GSML and CVDA was tested by means of a two-samples *t*-test (assuming unequal variances) or a Mann-Whitney *U*-test for normally distributed and count variables, respectively.

In order to assess the patterns of the co-variation between biodiversity indices and forest covariates (including microhabitats), we performed a two-block partial least squares analysis (2B-PLS). The two blocks were plots × biodiversity indexes and plots × forest structure and microhabitat type, respectively, and the analysis was done independently for GSML and CVDA. This statistical approach is well-suited for matrixes with comparatively low sample size and with highly correlated variables (Barker and Rayens, 2003; Carrascal et al., 2009). This statistical technique has been recently applied to several ecological studies, including forest ecosystems (Battipaglia et al., 2020; Innangi et al., 2019). 2B-PLS analysis finds latent variables that explain most of the covariance between two multivariate matrixes, returning variables that account as much as possible for the covariation between two sets of variables (Rohlf and Corti, 2000). The patterns of covariance between the two matrixes can be represented by a scatterplot for the first axis of the 2B-PLS, where the x-axis and the y-axis represent the two multivariate matrixes, respectively. These patterns of covariance can be interpreted using correlations, asserting patterns of positive or inverse correlation both within and between matrixes. All analyses were done in R 3.6.1 (R Core Team, 2019), using packages 'plsdepot' (Sanchez, 2012) and 'ggplot2' (Wickham, 2016).

3. Results

3.1. Forest structure and microhabitats

Measurements related to forest structure and microhabitat type are reported in [Table 4](#).

While both GSML and CVDA showed similar values of canopy cover and CWD volume (64.7 ± 3.4 vs. $61.4 \pm 4.2\%$ and 0.01 ± 0.004 vs. $0.01 \pm 0.008 \text{ m}^3 \text{ ha}^{-1}$, respectively), living tree volume in GSML was more than double than in Cilento (688.3 ± 48.6 vs. $331.1 \text{ m}^3 \text{ ha}^{-1}$, respectively). Additionally, GSML also showed higher basal area (61.8 ± 4.2 vs. $33.5 \pm 3.1 \text{ m}^2 \text{ ha}^{-1}$, respectively) and volume of stumps (0.35 ± 0.09 vs. $0.26 \pm 0.09 \text{ m}^3 \text{ ha}^{-1}$, respectively) than CVDA. In both areas, we found a large number of tree-related microhabitats on living trees (ca. 2002 vs. 1894 per ha, for GSML and CVDA, respectively). In detail, the most representative microhabitats were M21 (i.e., system of galleries on deadwood) and M22 (i.e., woody debris and/or stumps with saproxylic insect holes) for both the national parks, corresponding to the system of galleries on deadwood and woody debris and/or stumps with saproxylic insect holes, respectively.

For the remaining microhabitats, M3 (i.e., other fungal infections), M10 (i.e., cracks), and M12 (i.e., cavities with > 5 cm aperture) were generally more abundant in GSML, while M2 (i.e., living trees with fruiting bodies of *Fomitopsis pinicola*), M5 ($\geq 50\%$ of the crown broken), and M19 (i.e., bark loss) were more represented in CVDA.

3.2. Coleoptera communities

A total of 257 taxa were identified, namely 159 in GSML and 152 in CVDA. Among these taxa, 84 were shared between locations, while 75 and 98 taxa were found exclusively in GSML and CVDA, respectively. We found a fairly high contingent of saproxylic species included in the main IUCN risk categories: 22 species out of 72 in GSML; 22 species out of 52 in CVDA ([Table A](#)).

A list of 12 taxa that were all above the GWM threshold of 2% is reported in [Table 5](#).

All of these taxa occurred both in GSML and CVDA. Among these more abundant species, 50% were Elateridae, followed by Cerambycidae (17%). In general, the most abundant species was *Nothodes parvulus* (Elateridae), which accounted for 11% of the GWM.

In total, the communities of GSML were characterized by a relatively larger number of individuals when compared to CVDA (109 ± 14 vs. 97 ± 12 , respectively, Mann-Whitney U 91.5, $z = 1.5$, $p = 0.135$). The Simpson's dominance was significantly higher in GSML than in CVDA (0.14 ± 0.03 vs. 0.08 ± 0.01 , respectively, $t = 2.27$, $p = 0.034$). By contrast, all the other biodiversity indices were marginally higher in CVDA than in GSML, including the Pielou's evenness (0.86 ± 0.01 vs. 0.79 vs. 0.03 , respectively, $t = 2.09$, $p = 0.047$) ([Table 6](#)).

3.3. 2B-PLS analyses

The analyses put forward a separation between some locations in the upper-right quadrant (with Inc 4 & 5 at the extremes) compared to those in the lower-left quadrant (noticeably Ven 3 & 5) ([Fig. 2](#) and [Table 7](#)). The correlation within and between blocks showed that those locations with higher biodiversity indices (noticeably Shannon-Wiener, Margalef and Fisher's alpha indices) were positively correlated with higher volumes of CWD and the presence of M4 (i.e., $< 50\%$ of the crown broken). On the contrary, communities with higher Simpson's dominance were correlated with a higher canopy cover and the presence of M1 & M12 (i.e., Living trees with fruiting bodies of *Fomes fomentarius* and Cavities with > 5 cm aperture, respectively), albeit the correlations between the Forest Structure and Microhabitat type block were weaker if compared to the Biodiversity Indices block. As for CVDA ([Fig. 3](#) and [Table 7](#)), in GSML, the locations that segregated in the upper-left quadrant were led by all those from Motola plus Alb 100, while in the lower-right quadrant Alb 68 and 69 were found.

Once again, the driving variables from the Biodiversity Indices block were all measures of diversity, yet the most important ones, in this case, were the Margalef biodiversity index and the number of taxa. Noticeably, in CVDA, the number of individuals was also on the positive side of the correlation axis, while in GSML it was on the negative side. M5 (i.e., $\geq 50\%$ of the crown broken) was clearly positively correlated with the aforementioned biodiversity indices, followed again by M4, while CWD was less important. Again, Simpson's dominance was the most important indicator on the opposite site of the correlations yet with a weaker effect compared to GSML. Remarkably, M2 (i.e., Living trees with fruiting bodies of *Fomitopsis pinicola*) was the leading variable in covariation with communities with lower diversity and higher dominance. Most of the other Forest Structure and Microhabitat Type variables did not show a remarkable effect in explaining patterns of covariance neither within nor between locations.

Table 4
Forest structure and microhabitat type in GSML and CVDA.

	GSML															CVDA																			
	Incodera					Prati di Tivo					Venacuaro					Alburni					Molida														
	In_1	In_2	In_3	In_4	In_5	In_6	In_7	In_8	In_9	In_10	In_11	In_12	In_13	In_14	In_15	In_16	In_17	In_18	In_19	In_20	In_21	In_22	In_23	In_24	In_25	In_26	In_27	In_28	In_29	In_30	In_31	In_32	In_33	In_34	In_35
Forest Structure	617	400	778	434	770	1086	659	770	748	840	590	451	1007	900	562	624	882	694	246	140	427	659	553	240	234	194	183	756	222	133	245	243	316		
YOL_ba	56	37	73	42	71	102	68	61	65	72	50	37	76	78	54	56	84	65	29	21	45	42	37	19	31	23	27	58	27	20	32	43	44		
Clba	80	70	40	45	70	75	40	65	55	50	80	70	75	85	80	75	60	45	70	60	55	80	50	60	35	80	85	50	50	70	40	75			
CWD	0.014	0.027	0.005	0.064	0.030	0.002	0.064	0.005	0.007	0.002	0.003	0.006	0.006	0.004	0.001	0.000	0.009	0.001	0.002	0.002	0.006	0.002	0.001	0.001	0.014	0.003	0.001	0.001	0.000	0.001	0.024	0.119	0.005		
Stumps	0.014	0.016	0.044	0.306	0.562	0.126	0.090	1.629	0.537	0.245	0.165	0.011	0.614	0.211	0.260	0.142	0.445	0.447	0.747	0.424	0.072	0.000	0.000	0.766	0.117	0.071	0.070	0.589	0.317	0.074	0.000	1.160	0.005		
Microhabitats	M1	M2	M3	M4	M5	M7	M9	M10	M12	M16	M18	M19	M21	M22	M23	M1	M2	M3	M4	M5	M7	M9	M10	M12	M16	M18	M19	M21	M22	M23					
M1	1	-	-	-	1	-	1	-	-	-	-	-	-	1	-	-	1	-	1	1	-	-	-	-	1	-	2	-	1	-	-	-	-		
M2	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	3	4	2	1	-	1	-	-	-		
M3	2	4	1	1	-	1	-	2	-	1	-	3	2	1	1	-	2	3	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	1	2
M4	1	1	-	-	2	1	-	1	-	1	-	1	-	1	-	1	-	1	-	2	-	-	-	-	-	-	-	1	-	2	-	1	2	1	-
M5	-	-	1	2	1	-	1	-	-	-	-	-	-	-	1	-	-	-	-	1	1	2	-	-	-	-	-	-	-	1	-	1	2	3	-
M7	-	-	1	-	1	-	1	-	-	1	-	1	-	1	-	1	-	1	-	1	-	-	-	-	-	-	-	-	-	1	-	2	-	-	-
M9	2	1	1	-	1	-	1	-	1	-	1	-	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2	1	-	-
M10	1	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	1	-	2	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
M12	-	-	1	-	1	-	1	-	1	-	1	-	1	-	1	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M16	3	1	-	-	1	-	2	3	1	-	2	1	2	-	1	-	1	3	2	2	1	1	4	-	2	1	-	1	-	1	-	3	4	2	3
M18	2	1	1	-	3	2	1	3	1	4	2	-	2	4	-	1	4	1	-	-	1	-	-	-	1	-	2	1	2	1	-	2	-	1	-
M19	-	-	-	-	2	-	2	-	-	1	-	1	1	-	1	2	-	1	-	3	1	-	2	1	-	3	-	2	-	1	3	-	2	-	-
M21	9	11	8	4	9	15	13	6	9	6	11	4	7	7	6	4	9	11	13	8	6	5	9	15	7	5	8	9	19	6	9	13	9	-	-
M22	7	12	10	7	18	11	10	4	12	15	13	9	14	11	4	6	6	8	13	11	8	7	2	4	9	13	7	8	12	5	12	9	2	-	-
M23	2	-	-	1	-	-	-	1	-	1	-	1	1	-	1	-	1	2	-	1	1	-	-	-	-	1	-	1	-	1	-	1	1	-	-

Table 5
Absolute abundance for the 12 beetle species that were above the 2% threshold of the GWM, in GSML and CVDA.

Family	Species	Gran Sasso												Cilentò																				
		Incodara						Prati di Tivo						Venoscquaro						Alburni						Mofola								
		Inc.1	Inc.2	Inc.3	Inc.4	Inc.5	Inc.6	Prat.1	Prat.2	Prat.3	Prat.4	Prat.5	Prat.6	Ven.1	Ven.2	Ven.3	Ven.4	Ven.5	Ven.6	Alb.1	Alb.2	Alb.3	Alb.4	Alb.5	Alb.6	Mof.1	Mof.2							
Elaeidae	<i>Nolodes porvulus</i>	1	4	2	-	1	1	2	8	4	5	-	24	32	106	54	120	31	76	14	47	-	2	-	-	1	3	2	-	4	2	4		
Melyridae	<i>Dasytes plumbeus</i>	-	4	5	8	1	6	6	35	6	16	8	7	12	14	11	15	28	8	3	3	2	2	8	6	7	2	3	2	-	56	13	18	
Trogosinidae	<i>Nemacoma elongatum</i>	-	19	7	28	6	6	13	-	2	1	1	3	16	21	40	1	-	3	14	4	2	1	-	-	1	6	6	1	2	-	-	2	
Elaeidae	<i>Dalopius marginatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	13	10	12	13	10	17	10	18	3	7	10	5	8	
Cerambycidae	<i>Semaneilla melanura</i>	1	13	8	16	1	2	65	-	-	-	-	9	47	10	12	5	37	17	-	-	-	-	-	-	-	-	-	-	-	5	2	1	
Cerambycidae	<i>Phyllobius argentatus</i>	1	-	1	1	-	-	6	-	-	-	-	-	-	-	-	-	-	-	1	8	6	4	3	7	9	8	3	13	8	1	5	7	
Elaeidae	<i>Aborus kamorrboidalis</i>	-	4	2	3	6	2	1	2	1	2	4	6	2	2	4	1	1	3	1	1	-	4	2	1	1	2	3	1	1	5	1	7	5
Tenebrionidae	<i>Isomira muricata</i>	-	1	-	2	1	1	2	-	8	4	2	1	1	-	-	-	1	1	-	3	-	1	7	3	3	4	1	2	4	10	4	5	
Elaeidae	<i>Agrotes affinis</i>	1	1	6	9	2	3	2	1	1	1	-	-	4	3	2	1	-	3	-	2	9	1	1	-	-	5	5	4	3	4	1	1	1
Elaeidae	<i>Aborus subfuscus</i>	4	8	1	4	3	2	-	2	1	3	-	-	3	-	4	-	2	4	-	4	4	3	1	-	1	-	2	10	-	1	-	5	3
Cerambycidae	<i>Semaneilla senilis</i>	-	2	3	3	-	-	16	-	-	-	-	6	25	3	11	8	14	14	-	-	-	-	-	-	-	-	-	-	-	1	1	-	
Elaeidae	<i>Melampus villosus</i>	6	-	-	2	2	-	1	2	-	-	5	-	2	2	1	-	1	-	1	2	2	-	3	2	2	2	1	-	-	3	3	7	2
All other taxa		46	20	40	60	34	46	30	23	24	12	30	16	67	65	23	47	16	53	37	58	49	48	36	54	22	18	30	17	23	20	99	106	109

Table 6
Biodiversity indices for the beetle communities in GSML and CVDA.

Diversity Index	Gran Sasso												Cilento																				
	Incodara						Prati di Tivo						Venacquaro						Alburni						Motola								
	Inc. 1	Inc. 2	Inc. 3	Inc. 4	Inc. 5	Inc. 6	Prat. 1	Prat. 2	Prat. 3	Prat. 4	Prat. 5	Prat. 6	Ven. 2	Ven. 3	Ven. 4	Ven. 5	Ven. 6	Ven. 7	Alb. 100	Alb. 101	Alb. 171	Alb. 184	Alb. 194	Alb. 48	Alb. 69	Alb. 79	Alb. 80	Alb. 90	Alb. 91	Mot. 4	Mot. 5		
Taxa	36	28	30	47	53	30	27	22	24	16	22	16	39	40	24	36	17	33	32	49	35	34	28	38	22	20	31	56	26	24	54	50	58
Individuals	60	76	75	136	57	69	143	37	82	32	61	33	142	210	201	146	167	174	175	94	137	76	70	84	53	69	72	81	51	52	191	158	165
Dominance	0.05	0.12	0.06	0.07	0.05	0.05	0.24	0.07	0.21	0.10	0.11	0.11	0.08	0.11	0.33	0.16	0.53	0.12	0.22	0.05	0.15	0.07	0.09	0.06	0.09	0.11	0.06	0.08	0.09	0.08	0.11	0.07	0.04
Shannon	3.3	2.7	3.0	3.2	3.2	3.2	2.2	2.9	2.3	2.6	2.6	2.5	3.0	2.7	1.7	2.6	1.2	2.6	2.3	3.6	2.6	3.1	2.8	3.2	2.7	2.5	3.1	3.1	2.9	2.9	3.1	3.3	3.6
Margalef	8.5	6.2	6.7	9.4	7.9	6.8	5.2	5.8	5.2	4.3	5.1	4.3	7.7	7.3	4.3	7.0	3.1	6.2	6.0	10.6	6.9	7.6	6.4	8.4	5.3	4.5	7.0	8.0	6.4	5.8	10.1	9.7	11.2
Equality	0.92	0.80	0.90	0.84	0.93	0.94	0.67	0.93	0.71	0.92	0.85	0.89	0.81	0.73	0.54	0.72	0.43	0.75	0.66	0.91	0.74	0.87	0.85	0.89	0.88	0.85	0.90	0.86	0.89	0.90	0.77	0.84	0.89
Fisher's alpha	38	16	19	25	33	20	10	23	11	13	12	12	18	15	7	15	5	12	11	41	15	24	17	27	14	9	21	25	21	17	25	25	32

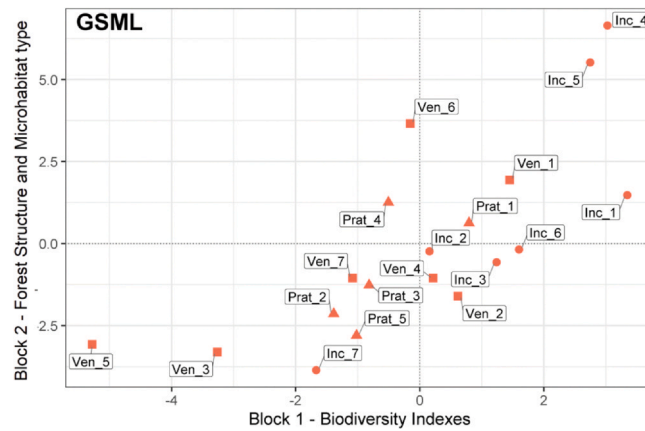


Fig. 2. Scatterplot of the first axis of the 2B-PLS for GSML. The x-axis represents biodiversity indices, while the y-axis represents forest structure and microhabitat type. The correlation within and between blocks is shown in Table 7.

Table 7

Correlations within and between blocks for the first axis of the 2B-PLS, with Block 1 corresponding to the x-axis in Figs. 3 and 4 (i.e., biodiversity indices), and Block 2 corresponding to the y-axis in Figs. 3 and 4 (i.e., forest structure and microhabitat type).

GSML			CVDA		
	Block 1	Block 2		Block 1	Block 2
Shannon	1.0		Margalef & Taxa	1.0	
Fisher alpha's & Margalef	0.9		Shannon	0.9	
Equitability	0.8		Individuals & Fisher's alpha	0.8	
Taxa	0.7			0.7	M5
	0.6			0.6	
	0.5	CWD		0.5	M4
	0.4	M4		0.4	CWD, M7 & M9
	0.3	M7, M5 & M10		0.3	G/HA, Stumps, Canopy, M16, M19 & M23
	0.2	M22 & M23		0.2	M3, M12 & M21
	0.1	VOL/HA & M9		0.1	M18
	0.0	G/HA, Stumps, M3, M16, M18 & M19		0.0	
	-0.1	M2 & M21	Equitability	-0.1	M22
	-0.2	M1 & M12		-0.2	M1
	-0.3	Canopy		-0.3	M10
Individuals	-0.4		Dominance	-0.4	
	-0.5			-0.5	
	-0.6			-0.6	
	-0.7			-0.7	M2
	-0.8			-0.8	
Dominance	-0.9			-0.9	
	-1.0			-1.0	

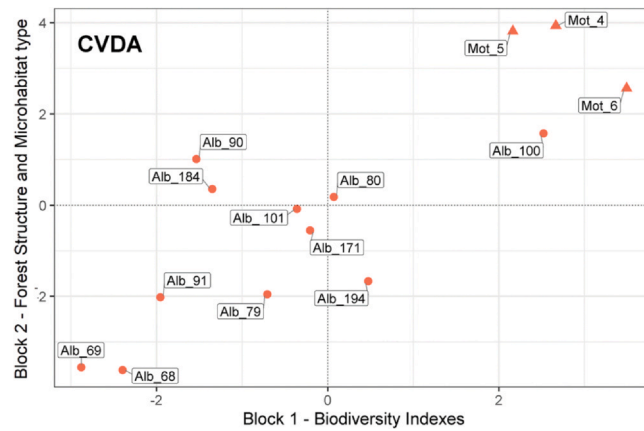


Fig. 3. Scatterplot of the first axis of the 2B-PLS for CVDA stand. The x-axis represents biodiversity indices, while the y-axis represents forest structure and microhabitat type. The correlations within and between blocks is shown in Table 7.

4. Discussion

In this study, the importance of forest biodiversity indicators was studied by analyzing the covariation between beetle communities and forest characteristics in two national parks. The beech forests here investigated have an old legacy of forest management, which has induced a reduction of the structural complexity, but also a simplification of the overall forest ecosystem, with negative effects on the abundance of the saproxylic communities (Bani et al., 2018; Parisi et al., 2018). The biodiversity indices (Dominance, Shannon, Margalef, Equitability and Fisher's alpha) were mainly related to the structural complexity of these forests and microhabitat abundance, although with differences between stands in the two protected areas.

Diversity indices showed quite similar and homogeneous diversity and specific richness values in GSML and CVDA. In particular, this was confirmed by nonsignificant differences in Shannon and Margalef indices, indicating a lack of similarity in the distribution of dominant species. However, the alpha diversity suggested differences in specific composition between the two protected areas. Regardless of the low diversity, a significant fraction of diversity was fully recovered in the different trophic categories found. Nevertheless, the covariance analysis indicated that beetle communities included both abundant and rare species. Therefore, the structure of the beetle community was not determined by the type of habitat, as the beech forests were similar in terms of fauna and vegetation.

From a quantitative point of view, the Elateridae family dominated for both areas, although with two different species that led the statistical analyses (*Nothodes parvulus* and *Dalopius marginatus*, for GSML and CVDA, respectively). *N. parvulus* species was the most abundant (22%). The abundance of the two taxa influenced the diversity analyses, as total individuals.

The main habitats related to beetle fauna did not show significant differences in terms of deadwood volume (m^3 , CWD and stumps) and abundance of microhabitats (see Table 4). CVDA showed a more even distribution in the number of species than GSML. This could be due to more stable environmental conditions, as confirmed by the biodiversity indices (Margalef and Taxa indices, Table 6). These features might guarantee the availability of bio-habitats over time and space for saproxylic fauna, promoting stability of the insect community.

In CVDA, the weak positive correlation between the abundance of beetles and the basal area was likely due to the absence of cutting activities, which created an un-even aged structure. Indeed, the value of the basal area (61.8 vs. $33.5 \text{ m}^2 \text{ ha}^{-1}$, for GSML and CVDA, respectively), is consistent with the control category (basal area greater than $29 \text{ m}^2 \text{ ha}^{-1}$) proposed by Keddy and Drummond (1996) for old-growth forests. Nevertheless, the long-lasting effects of past management still influence the actual forest structure (Lombardi et al., 2012). The relative structural homogeneity of these forests gave rise to a poor association of forest structure with beetle diversity (Parisi et al., 2016; Sabatini et al., 2016). We hypothesize that the absence of forest gaps and the forest continuity, resulting from the past forest management, but also the absence of differentiated forest development stages, induced an homogenization of microclimatic conditions. In fact, over 98% of the beetles sampled in this study belong to the same families (35 vs. 36 families, for GSML and CVDA, respectively). By contrast, spatial differentiation and vertical heterogeneity could be more easily observed in complex forest structures, such as in old-growth forests (Paillet et al., 2018), affecting light, moisture, and temperature, as well as other habitat characteristics required by beetle communities.

Several authors reported that forest management might affect saproxylic richness and distribution (Brin et al., 2009; Buse et al., 2010; Gibb et al., 2006; Lassaue et al., 2011; Siitonen, 2001; Parisi et al. 2019, 2020a). Studies on saproxylic beetles in European forests revealed that many species, often at high risk of extinction (Seibold et al., 2015), which are active on deadwood of large diameters and exposed to the sun, could be strongly influenced by forest management (Gossner et al., 2013; Parisi et al., 2020b). Yet, their abundance could be negatively affected by the increase of continuous canopy cover (Schall et al., 2017), but also by the loss of large veteran trees (Bauhus et al., 2009). In several protected beech forests in Central and Southern Italy,

saproxylic beetles ranged from 25% to 55% of the whole beetle fauna, typical of unmanaged forests in the Apennine mountain (Cocciufa et al., 2014; Parisi et al., 2020a).

The amount of CWD, the density of microhabitats occurring on living trees and canopy cover (visually estimated as %) significantly influenced the beetle communities in these beech forest stands. We observed variations between the beetle species that grow on deadwood in comparison with those occurring on the ground, on dead branches, or on fruiting bodies. Similar results were found in silver fir and beech forests of central Italy (Parisi et al., 2020a), where the volume of deadwood and the abundance of microhabitats were used as a predictive factor for beetles included in the IUCN red list.

In GSML, the most abundant microhabitats were those related to deadwood (i.e., fungal infections, clefts into the sapwood and woodpecker cavities). Whereas, in CVDA, microhabitats linked to living trees prevailed (i.e., living trees with fruiting bodies, crown broken and bark loss). However, some microhabitats M4 (i.e., < 50% of the crown broken) and M5 (i.e., ≥50% of the crown broken) positively influenced the diversity of beetles in both the study sites, suggesting a differentiation of ecological niches where specialized organisms occur which live in large trees with broken crown. We also observed how the most abundant microhabitats (i.e., system of galleries on deadwood, woody debris and/or stumps with saproxylic insect holes) were linked to the trophic activity of many saproxylic species. The abundance of tree-related microhabitats is, in general, strictly correlated to trees of large diameters and veteran trees (Regnery et al., 2013).

Results showed that the presence of large dead trees, but also specific types of microhabitats (e.g., M1 and M2 - living trees with fruiting bodies of *Fomes fomentarius* or *Fomitopsis pinicola*) largely influenced the diversity of Coleoptera communities, suggesting a high variability among the species that feed on dead substrates and associated fungi (see Table 7). These ecological niches represent the optimal substrate for the oviposition of primary saproxylic beetles on living trees (i.e., Cerambycidae, Lucanidae, Curculionidae, Bostrichidae, Tenebrionidae and Throscidae), fundamental for the correct functioning of the forest ecosystem (Lassauce et al., 2011).

Many sampled species were related to living trees and deadwood components of the forest, providing a representative matrix of the beetle community. From a quantitative point of view, the number of saproxylic species would depend on the volume of CWD, while the decay stage of CWD should influence highly specialized taxa, often found in Red Lists (Lonsdale et al., 2008; Dodelin, 2010). Furthermore, the different species depending on deadwood do not colonize it directly by feeding at the expense of other decomposers (secondary saproxylic). In fact, many species of beetles may feed on the fungal mycelium (Esseen et al., 1997).

The activity and abundance of keystone species would determine “the integrity of the community” and its unaltered persistence over time (Paine, 1969), as evidenced by the dominance index, resulting in the maintenance of species diversity (Parisi et al., 2020c). This condition is frequent in ecosystems with a high degree of naturalness, and where the biotic components are in equilibrium (Thorn et al., 2020a). Indeed, we observed rather high variability of all the trophic categories (see Table A).

Several studies have empirically established the dependence of species and groups on specific microhabitats (Bouget et al., 2014; Larrieu et al., 2018; Percel et al., 2019; Siitonen, 2012), though correlations between species richness or diversity with microhabitat metrics generally show moderate association (Paillet et al., 2018). Here, a positive correlation between the occurrence of microhabitats with the presence of fungi and the richness of beetle species was observed. This correlation and those between biodiversity indices and forest components (Table 7) were relevant for both the structural characteristics of the forests and for the abundance of deadwood in relation to the diversity of beetle species. The highest correlations between structural attributes, microhabitat types and beetle richness emerged when the community was considered as a whole and separated for the two protected areas. The clear separation between locations in GSML (Inc 4 & 5 and Ven 3 & 5) could be attributable to differences in forest structure and deadwood abundance (data not shown) compared to the other plots, affecting the beetle communities; similar observations were made in other locations (Motola, Alb 100, Alb 68 and 69) in CVDA (Figs. 2 and 3). Therefore, we may conclude that the response of species richness to deadwood availability was relatively good (cf. Sabatini et al., 2016).

Our results are in line with the findings of Vanderwel et al. (2006), regarding the correlation between beetle diversity and CWD volume, but not with those regarding the composition of the insect community. The correlations highlighted in Table 7 further highlighted the complexity of the interrelationships, emphasizing the importance of the availability of resources in both qualitative and quantitative terms. Similar results were obtained in other studies concerning CWD (e.g., Heilmann-Clausen and Christensen, 2005).

The canopy cover did not have a clear influence on biodiversity indices. This could be attributable to the early stage of old-growth forest structure in these forest stands (Lombardi et al., 2010; Sabatini et al., 2016). From the analysis of the canopy cover, in both GSML and CVDA forests, we might infer a rather open structure. In conditions of relatively high irradiance reaching the ground, a high density and diversity of understory vegetation (Sabatini et al., 2014) and lichens (Aragon et al., 2010) can be expected. Forest gaps are generally characterized by a greater abundance of understory plants that may represent a key resource for many saproxylic beetles (Bouget et al., 2014). Lachat et al. (2016) showed that the abundance and composition of the beetles were greater in the sunny areas inside and outside the forest, but these authors did not find differences in species richness.

To improve our understanding of trade-offs and synergies between forest management and biodiversity conservation, long-term monitoring of forest ecosystems strategies should be implemented (Durak, 2012). Long-term monitoring of these habitats provides important information on their resilience to disturbance. Sustainable forest management strategies adopted in protected areas may also contribute to maintain a certain degree of biodiversity, although appropriate biodiversity indices and conservation status indicators need to be defined first at the habitat level. Nevertheless, a high level of diversity is known to be an important indicator of the conservation status of both managed and unmanaged forest ecosystems (Kutnar et al., 2015).

4.1. Implications for conservation

Saproxylic species represent an important percentage of forest biodiversity, which in some groups can reach 60%. Overall, about 25% of all forest species are saproxylic (Paillet et al., 2010) and these organisms are known to be highly threatened (Davies et al., 2008). Intensive utilization and deadwood removal had major impacts on forest ecosystems and associated species in Mediterranean mountain systems (e.g., Motta et al., 2006), which caused a decrease in biodiversity (Cálix et al., 2018). Based on the present results, conservation measures, such as the retention habitat trees, snags or lying deadwood, were confirmed of key elements for saproxylic species (Kraus and Krumm, 2013).

We recommend to promote deadwood retention, habitat heterogeneity, and canopy openness in these protected beech forests. In these forests, long-term monitoring plots should be established for elucidating the role of species composition, habitat availability, and microclimatic conditions on biodiversity at different spatial scales (from the single plot to the whole park), as well as to explore the effects of linking mixed management systems with large conservation areas to preserve biodiversity from a landscape perspective (Heikkala et al., 2017).

5. Conclusions

Overall, our results indicate that forest structure and tree-related microhabitats were the most important variables for determining the biodiversity of beetle communities in these Mediterranean mountain beech forests. In particular, the amount of deadwood positively influenced saproxylic beetle communities. Forest structure, deadwood abundance, canopy cover, and microhabitat type were important indicators for monitoring biodiversity, including threatened species, in line with the objectives of the EU Biodiversity Strategy for 2030 (EU Biodiversity Strategy for 2030). This information is particularly important for implementing the objectives of sustainable forest management and for planning strategies aimed at the conservation of biodiversity in protected mountain environments (Burrascano et al., 2008; Pohjanmies et al., 2019).

Indicator species should be used to determine conservation areas with high ecological value, having a more limited distribution and being more vulnerable to disturbances than generalist species (Schouten et al., 2010). Although we found as many as 7 species included in the IUCN red list, rare and threatened taxa were collected only in some sites and with few individuals and could hardly be used as indicators (whole saproxylic vs. threatened species, Table A). Traits characterizing the biology of saproxylic and non-saproxylic beetles and the links to the forest components make it possible to connect the extinction risk to human pressure or the conservation response. This is useful for drawing implications for conservation strategies at the landscape scale and for increasing the resilience of these mountain ecosystems threatened by climate and land-use changes.

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Declaration of Competing Interest

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

See Appendix Table A1.

Table A1

List of species of Coleoptera and number of specimens collected from GSML and CVDA national parks.

Families	Species	IUCN	CT	GSML	CVDA
Anthribidae	Platyrhinus resinosus (Scopoli, 1763)	LC	XY	1	
Anthribidae	Platystomos albinus (Linnaeus, 1758)	LC	XY	1	2
Attelabidae	Neocoenorrhinus interpunctatus (Stephens, 1831)				1
Biphylidae	Diplocoelus fagi (Chevrolat, 1837)	LC	SX		2
Brentidae	Holotrichapion pisi (Fabricius, 1801)				2
Buprestidae	Agrilus angustulus (Illiger, 1803)	LC	XY		1
Buprestidae	Agrilus graminis Gory & Laporte de Castelnau, 1837	LC	XY	1	
Buprestidae	Agrilus olivicolor Kiesenwetter, 1857	LC	XY		2
Byturidae	Byturus tomentosus (De Geer, 1774)			1	1
Cantharidae	Cantharis decipiens Baudi, 1871				7
Cantharidae	Malthinus deceptor Baudi, 1983			1	1
Cantharidae	Rhagonycha lignosa (Müller, 1764)			1	
Cantharidae	Rhagonycha lutea (Müller, 1764)				1
Cantharidae	Rhagonycha nigriceps (Waltl, 1838)			1	
Cantharidae	Rhagonycha nigrosuta Fiori, 1900				2
Cerambycidae	Acanthocinus xanthoneurus (Mulsant & Rey, 1852)	NT	XY		1
Cerambycidae	Alosterna tabacicolor (De Geer, 1775)	LC	XY	3	
Cerambycidae	Leopus nebulosus (Linnaeus, 1758)	LC	XY		1
Cerambycidae	Oxymirus cursor (Linnaeus, 1758)	LC	XY	1	
Cerambycidae	Paracorymbia fulva (De Geer, 1775)	LC	XY	1	
Cerambycidae	Phymatodes testaceus (Linnaeus, 1758)	LC	XY		1
Cerambycidae	Pseudovadonia livida (Fabricius, 1777)	LC	XY	1	22
Cerambycidae	Pyrrhidium sanguineum (Linnaeus, 1758)	LC	XY	1	
Cerambycidae	Rhagium mordax (De Geer, 1775)	LC	XY		1
Cerambycidae	Rutpela maculata (Poda, 1761)	LC	XY	4	
Cerambycidae	Saphanus piceus (Laicharting, 1784)	NT	XY	3	
Cerambycidae	Stenurella melanura (Linnaeus, 1758)	LC	XY	244	8
Cerambycidae	Stenurella sennii Sama, 2002	DD	XY	98	2
Cerambycidae	Stictoleptura rubra (Linnaeus, 1758)	LC	XY	1	
Cerambycidae	Tetrops praeustus (Linnaeus, 1758)	LC	XY		1
Cerambycidae	Xylotrechus arvicola (Olivier, 1795)	LC	XY		3
Chrysomelidae	Aphthona euphorbiae (Schrank, 1781)				1
Chrysomelidae	Aphthona venustula (Kutschera, 1861)				10
Chrysomelidae	Galerucella lineola (Fabricius, 1781)				7
Cerylonidae	Cerylon ferrugineum Stephens, 1830	LC	MY	5	1
Ciidae	Cis boleti (Scopoli, 1763)	LC	MB	3	
Ciidae	Rhopalodontus perforatus (Gyllenhal, 1813)	LC	MB		1
Cleridae	Opilo mollis (Linnaeus 1758)	LC	PR	1	2
Cleridae	Tillus elongatus (Linnaeus 1758)	NT	PR	6	9
Cleridae	Thanasimus formicarius (Linnaeus, 1758)	LC	PR		1
Coccinellidae	Subcoccinella vigintiquatuorpunctata (Linnaeus, 1758)				1
Corylophidae	Arthrolips nana (Mulsant & Rey, 1861)	DD	MY	1	1
Cryptophagidae	Cryptophagus sp. A			2	
Cryptophagidae	Cryptophagus sp. B			1	1
Curculionidae	Acalles parvulus Boheman, 1837	LC	SX		1
Curculionidae	Anisandrus dispar (Fabricius, 1793)	LC	MY	1	
Curculionidae	Ceutorhynchus picitarsis Gyllenhal, 1837				1
Curculionidae	Dichotrachelus bensai Solari & Solari, 1903			1	
Curculionidae	Ernoporicus fagi (Fabricius, 1798)	LC	XY		3
Curculionidae	Gymnetron veronicae (Germar, 1821)				1
Curculionidae	Hylastinus obscurus (Marsham, 1802)	LC	XY	2	
Curculionidae	Hylesinus toranio (Danthoine, 1788)	LC	XY		6
Curculionidae	Lymantror coryli (Perris, 1853)	VU	XY		1
Curculionidae	Orchestes fagi (Linnaeus, 1758)			4	15
Curculionidae	Phyllobius argentatus (Linnaeus, 1758)			11	64
Curculionidae	Phyllobius longipilis Boheman, 1843			20	
Curculionidae	Phyllobius romanus Faust, 1890			11	41
Curculionidae	Polydrusus aeratus (Gravenhorst, 1807)			2	
Curculionidae	Polydrusus cervinus (Linnaeus, 1758)			2	
Curculionidae	Polydrusus impar Gozis, 1882				1
Curculionidae	Polydrusus neapolitanus Desbrochers des Loges, 1871				1
Curculionidae	Polydrusus pterygomalis Boheman, 1840			2	
Curculionidae	Polydrusus sericeus Goeze, 1777				2
Curculionidae	Polydrusus transalpinus Daniel & Daniel, 1906			12	
Curculionidae	Polydrusus raverae Solari & Solari, 1904				1
Curculionidae	Rhynchaenus fagi (Linnaeus, 1758)			10	2
Curculionidae	Rhyncolus elongatus (Gyllenhal, 1827)	LC	SX		1
Curculionidae	Scolytus intricatus (Ratzeburg, 1837)	LC	XY	2	8
Curculionidae	Scolytus multistriatus (Marsham, 1802)	LC	XY		3

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Table A1 (continued)

Families	Species	IUCN	CT	GSML	CVDA
Curculionidae	<i>Taphrorhynchus bicolor</i> (Herbst, 1793)	LC	XY	1	1
Curculionidae	<i>Taphrorhynchus villifrons</i> (Dufour, 1843)	LC	XY	1	
Curculionidae	<i>Trypodendron domesticum</i> (Linnaeus, 1758)	LC	MY	1	2
Curculionidae	<i>Tychius meliloti</i> Stephens, 1831				1
Curculionidae	<i>Xyleborinus saxesenii</i> (Ratzeburg, 1837)	LC	MY	4	
Curculionidae	<i>Xylosandrus germanus</i> (Blandford, 1894)			5	
Dascillidae	<i>Dascillus cervinus</i> (Linnaeus, 1758)			2	3
Dermestidae	<i>Anthrenus fuscus</i> Olivier, 1789			1	
Dermestidae	<i>Globicornis emarginata</i> (Gyllenhal, 1808)	LC	NI	1	
Dermestidae	<i>Globicornis luckowi</i> Herrmann, Háva & Kadej, 2011	NT	NI	3	1
Elateridae	<i>Agriotes infuscatus</i> Desbrochers des Loges, 1870			21	24
Elateridae	<i>Agrypnus murinus</i> (Linnaeus, 1758)				1
Elateridae	<i>Ampedus quercicola</i> (Buysson, 1887)	LC	PR		1
Elateridae	<i>Athous haemorrhoidalis</i> (Fabricius, 1801)			27	29
Elateridae	<i>Athous puncticollis</i> Kiesenwetter, 1858			1	6
Elateridae	<i>Athous subfuscus</i> (Müller, 1764)			22	13
Elateridae	<i>Athous vittatus</i> (Fabricius, 1793)			7	8
Elateridae	<i>Cardiophorus vestigialis</i> Erichson, 1840				1
Elateridae	<i>Dalopius marginatus</i> (Linnaeus, 1758)				134
Elateridae	<i>Denticollis linearis</i> (Linnaeus, 1758)	CR	PR	1	1
Elateridae	<i>Dicronychus cinereus</i> (Herbst, 1784)				9
Elateridae	<i>Drilus flavescens</i> Olivier, 1790				1
Elateridae	<i>Hemicrepidius hirtus</i> (Herbst, 1784)			1	2
Elateridae	<i>Hypoganus inunctus</i> (Panzer, 1795)	EN	PR		1
Elateridae	<i>Idolus picipennis</i> (Bach, 1852)				2
Elateridae	<i>Limonius minutus</i> (Linnaeus, 1758)				7
Elateridae	<i>Melanotus villosus</i> (Geoffroy in Fourcroy, 1785)	LC	PR	11	15
Elateridae	<i>Nothodes parvulus</i> (Panzer, 1799)			397	79
Elateridae	<i>Pheletes quercus</i> (Olivier, 1790)				1
Elateridae	<i>Stenagostus rhombeus</i> (Olivier, 1790)	VU	PR	12	3
Erotylidae	<i>Triplax elongata</i> Lacordaire, 1842	NT	MB	1	1
Erotylidae	<i>Triplax lacordairii</i> Crotch, 1870	NT	MB	3	1
Erotylidae	<i>Triplax lepida</i> (Faldermann, 1837)	NT	MB	4	
Erotylidae	<i>Triplax marseuli</i> Bedel, 1864	NT	MB		1
Erotylidae	<i>Triplax russica</i> (Linnaeus, 1758)	LC	MB		2
Eucnemidae	<i>Eucnemis capucina</i> Ahrens, 1812	NT	SX		1
Eucnemidae	<i>Hylis cariniceps</i> (Reitter, 1902)	NT	SX	1	14
Eucnemidae	<i>Hylis simonae</i> (Olexa, 1970)	NT	SX	8	14
Eucnemidae	<i>Isorhipis melasoides</i> (Laporte de Castelnau, 1835)	LC	SX		8
Eucnemidae	<i>Melasis buprestoides</i> (Linnaeus, 1760)	LC	SX	3	3
Eucnemidae	<i>Microrrhagus pygmaeus</i> (Fabricius, 1793)	NT	SX		2
Kateretidae	<i>Brachypterolus linariae</i> (Stephens, 1830)				2
Histeridae	<i>Atholus duodecimstriatus</i> (Schrank, 1781)				1
Histeridae	<i>Paromalus flavicornis</i> (Herbst, 1792)	LC	PR	1	
Laemophloeidae	<i>Laemophloeus monilis</i> (Fabricius, 1787)			7	6
Lampyridae	<i>Lampyrus vesuvius vesuvius</i> (Geisthardt, 2007)			1	5
Lampyridae	<i>Luciola lusitanica</i> (Charpentier, 1825)			3	2
Latridiidae	<i>Cartodere nodifer</i> (Westwood, 1839)	LC	MY	1	1
Latridiidae	<i>Enicmus atriceps</i> Hansen, 1962	DD	MY	4	4
Latridiidae	<i>Enicmus brevicornis</i> (Mannerheim, 1844)	LC	MY	5	15
Latridiidae	<i>Enicmus fungicola</i> Thomson, 1868	LC	MY		1
Latridiidae	<i>Enicmus testaceus</i> (Stephens, 1830)	LC	MY	1	2
Leiodidae	<i>Agathidium varians</i> Beck, 1817	LC	MY	3	2
Leiodidae	<i>Leiodes</i> sp. A				3
Leiodidae	<i>Leiodes</i> sp. B				1
Lucanidae	<i>Platycerus caprea</i> (De Geer, 1774)	LC	SX	1	
Lucanidae	<i>Platycerus caraboides</i> (Linnaeus, 1758)	LC	SX		4
Lucanidae	<i>Sinodendron cylindricum</i> (Linnaeus, 1758)	LC	SX	2	9
Melandryidae	<i>Abdera quadrifasciata</i> (Curtis, 1829)	NT	MY	3	
Melandryidae	<i>Conopalpus testaceus</i> (Olivier, 1790)	NT	MY	9	5
Melandryidae	<i>Melandrya caraboides</i> (Linnaeus, 1760)	NT	MY		2
Melandryidae	<i>Phloiodya tenuis</i> (Hampe, 1850)	NT	MY	1	
Melyridae	<i>Aplocnemus nigricornis</i> (Fabricius, 1793)	LC	PR	16	
Melyridae	<i>Danacea ambigua</i> (Mulsant & Rey, 1868)			17	7
Melyridae	<i>Dasytes caeruleus</i> (De Geer, 1774)	LC	PR	3	
Melyridae	<i>Dasytes plumbeus</i> (Müller, 1776)	LC	PR	191	122
Monotomidae	<i>Rhizophagus nitidulus</i> (Fabricius, 1798)	NT	MY	1	
Mordellidae	<i>Mordellistena pumila</i> (Gyllenhal, 1810)				2
Mordellidae	<i>Mordellochroa milleri</i> (Emery, 1878)			3	1

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Table A1 (continued)

Families	Species	IUCN	CT	GSML	CVDA
Mycetophagidae	Litargus connexus (Geoffroy, 1785)	LC	MY		1
Mycetophagidae	Mycetophagus atomarius (Fabricius, 1787)	LC	MY	2	
Mycetophagidae	Triphyllus bicolor (Fabricius, 1777)	LC	MY	3	2
Nitidulidae	Acanthogethes brevis (Sturm, 1845)				1
Nitidulidae	Brassicogethes aeneus (Fabricius, 1775)				1
Nitidulidae	Brassicogethes viridescens (Fabricius, 1787)			1	30
Nitidulidae	Carpophilus nepos Murray, 1854			1	
Nitidulidae	Eपुरaea melanocephala (Marsham, 1802)	LC	MY		1
Nitidulidae	Eपुरaea unicolor (Olivier, 1790)	LC	SF		1
Nitidulidae	Eपुरaea fuscicollis (Stephens, 1835)	LC	SF	4	
Nitidulidae	Genistogethes erichsoni (Brisout de Barneville, 1863)				1
Nitidulidae	Lamiogethes brunnicornis (Sturm, 1845)				1
Nitidulidae	Lamiogethes bidens (Brisout de Barneville, 1863)				1
Nitidulidae	Meligethes atratus (Olivier, 1790)			1	
Nitidulidae	Sagittogethes distinctus (Sturm, 1845)			1	
Nitidulidae	Soronia oblonga Brisout de Barneville, 1863	LC	SF		5
Nitidulidae	Thalycra fervida (Olivier, 1790)				3
Oedemeridae	Oedemera podagrariae (Linnaeus 1767)				2
Ptinidae	Dorcatoma punctulata Mulsant & Rey, 1864	VU	XY		1
Ptinidae	Grynobius planus (Fabricius, 1787)	LC	XY	3	
Ptinidae	Hedobia pubescens (Olivier, 1790)	LC	XY	1	1
Ptinidae	Hemicoelus costatus Aragona, 1830	LC	XY	23	20
Ptinidae	Ochina latreilli (Bonelli, 1812)	NT	XY		2
Ptinidae	Ptilinus pectinicornis (Linnaeus, 1758)	LC	XY	39	9
Ptinidae	Ptinomorphus imperialis (Linnaeus, 1767)	LC	XY	20	
Ptinidae	Ptinomorphus regalis (Duftschmid, 1825)	LC	XY		4
Ptinidae	Stegobium paniceum (Linnaeus, 1758)			1	
Salpingidae	Salpingus planirostris (Fabricius, 1787)	LC	SX	10	5
Salpingidae	Vincenzellus ruficollis (Panzer, 1794)	LC	MY		1
Scarabaeidae	Anoplotrupes stercorosus (Hartmann in Scriba, 1791)			4	1
Scarabaeidae	Aphodius borealis Gyllenhal, 1827			1	2
Scarabaeidae	Aphodius niger (Illiger, 1798)			1	
Scarabaeidae	Aphodius rufa (Moll, 1782)				4
Scarabaeidae	Aphodius rufipes (Linnaeus, 1758)			5	6
Scarabaeidae	Aphodius sticticus (Panzer, 1798)			2	6
Scarabaeidae	Aphodius zenkeri Germar, 1813			2	
Scarabaeidae	Geotrupes stercorarius (Linnaeus, 1758)			1	
Scarabaeidae	Gnorimus nobilis (Linnaeus, 1758)	NT	SX	1	2
Scarabaeidae	Rizothrogus sp.				1
Scarabaeidae	Serica brunnea (Linnaeus, 1758)				3
Scirtidae	Prionocyphon serricornis (Müller, 1821)	NT	HW	2	1
Scirtidae	Elodes cf. gredleri Kiesenwetter, 1863			1	
Scirtidae	Elodes cf. marginata Fabricius, 1798			1	
Scraptiidae	Anaspis costai Emery, 1876	VU	SX	1	
Scraptiidae	Anaspis nigripes Brisout de Barneville 1866			2	6
Scraptiidae	Anaspis rufilabris (Gyllenhal, 1827)	EN	SX	5	
Silphidae	Nicrophorus interruptus Stephens, 1830			5	
Silphidae	Nicrophorus vespilloides (Herbst, 1783)				1
Staphylinidae	Aleochara intricata Mannerheim, 1830				1
Staphylinidae	Aleochara sparsa Heer, 1839			1	1
Staphylinidae	Anthophagus fauveli caprai Koch, 1933			9	3
Staphylinidae	Anthophagus torretassoi torretassoi Koch, 1933			1	
Staphylinidae	Atheta crassicornis (Fabricius, 1793)				3
Staphylinidae	Atheta taxiceroides Munster, 1932			1	4
Staphylinidae	Atrecus affinis (Paykull, 1789)	LC	PR	2	1
Staphylinidae	Bisnius fimetarius (Gravenhorst, 1802)				1
Staphylinidae	Dinothenarus flavocephalus (Goeze, 1777)				1
Staphylinidae	Eusphalerum bargagli (Luze, 1910)			1	
Staphylinidae	Eusphalerum baudii (Fiori, 1894)				14
Staphylinidae	Eusphalerum clavipes (Scriba, 1868)			2	
Staphylinidae	Eusphalerum italicum italicum (Koch, 1938)			2	
Staphylinidae	Eusphalerum martinae (Zanetti, 2004)				4
Staphylinidae	Eusphalerum signatum angulatum (Luze, 1911)			18	4
Staphylinidae	Gyrohypus fracticornis (Müller, 1776)				1
Staphylinidae	Habrocerus capillaricornis (Gravenhorst, 1806)			1	
Staphylinidae	Haploglossa cf. picipennis (Gyllenhal, 1827)				1
Staphylinidae	Lordithon lunulatus (Linnaeus, 1760)			2	3
Staphylinidae	Neuraphes sp.				1
Staphylinidae	Ocypus italicus (Aragona, 1830)			3	2

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Table A1 (continued)

Families	Species	IUCN	CT	GSML	CVDA
Staphylinidae	<i>Ontholestes murinus</i> (Linnaeus, 1758)				1
Staphylinidae	<i>Paraphloeostiba gayndahensis</i> (MacLeay, 1873)			1	
Staphylinidae	<i>Philonthus carbonarius</i> (Gravenhorst, 1802)				1
Staphylinidae	<i>Philonthus cognatus</i> (Stephens, 1832)				1
Staphylinidae	<i>Philonthus concinnus</i> (Gravenhorst, 1822)				1
Staphylinidae	<i>Philonthus decorus</i> (Gravenhorst, 1802)			1	1
Staphylinidae	<i>Philonthus laminatus</i> (Creutzer, 1799)			1	
Staphylinidae	<i>Philonthus succicola</i> (Thomson, 1860)				1
Staphylinidae	<i>Phloeopora corticalis</i> (Gravenhorst, 1802)	LC	UN	1	
Staphylinidae	<i>Phloeostiba plana</i> (Paykull, 1792)	LC	SX	1	
Staphylinidae	<i>Platystethus nitens</i> (Sahlberg, 1832)				1
Staphylinidae	<i>Quedius cinctus</i> (Paykull, 1790)			1	3
Staphylinidae	<i>Quedius collaris italicus</i> Gridelli, 1925				
Staphylinidae	<i>Quedius humeralis</i> (Stephens, 1832)				2
Staphylinidae	<i>Quedius laticollis</i> Gridelli, 1924			2	
Staphylinidae	<i>Quedius levicollis</i> (Brullé, 1832)				1
Staphylinidae	<i>Quedius nigrocaeruleus</i> (Fauvel, 1876)				1
Staphylinidae	<i>Quedius picipes</i> (Mannerheim, 1830)				1
Staphylinidae	<i>Tachinus humeralis</i> Gravenhorst, 1802			1	
Staphylinidae	<i>Tachyporus nitidulus</i> (Fabricius, 1781)				5
Tenebrionidae	<i>Accanthopus velikensis</i> (Piller & Mitterpacher, 1783)	LC	SX	9	5
Tenebrionidae	<i>Cteniopus sulphureus</i> (Linnaeus, 1758)				1
Tenebrionidae	<i>Gonodera luperus</i> (Herbst, 1783)			5	22
Tenebrionidae	<i>Gonodera metallica</i> (Küster, 1850)			1	8
Tenebrionidae	<i>Helops coeruleus</i> (Linnaeus, 1758)	LC	SX	1	
Tenebrionidae	<i>Isomira marcida</i> (Kiesenwetter, 1863)			25	50
Tenebrionidae	<i>Mycetochara linearis</i> (Illiger, 1794)	LC	SX	2	7
Tenebrionidae	<i>Omophlus lepturoides</i> (Fabricius, 1787)				1
Tenebrionidae	<i>Pseudocistela ceramboides</i> (Linnaeus, 1760)	NT	SX	1	
Tenebrionidae	<i>Stenomax aeneus</i> (Scopoli, 1763)	LC	SX		1
Trogossitidae	<i>Nemozoma elongatum</i> (Linnaeus, 1760)	LC	PR	71	24
Trogossitidae	<i>Thymalus limbatus</i> (Fabricius, 1787)			2	
Zopheridae	<i>Corticus celtis</i> Dejean, 1821	LC	SX		2
Zopheridae	<i>Coxelus pictus</i> (Sturm, 1807)	LC	SX	3	3

IUCN = Red List Categories (Audisio et al. 2015). CR = Critically endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern, DD = Data Deficient.

CT = Trophic Categories. XY = xylophagous (also on healthy trees), SX = saproxylophagous (on dead wood and woody rotting material, including woodmould), PR = predator (as larvae and/or adults) of Sx/xy or of other saproxylic insects, MY = mycophagous (on hyphae of saproxylic fungi or yeasts, and myxomycetes, mostly under bark), MB = mycetobiontic on carpophora of large Polyporales and other fungi living on old trees and stumps, NI (CO) = inhabiting birds' and small mammals' nests in hollow trees, CO = commensal of Sx/xy or of other saproxylic insects, SF = sap-feeder on trees attacked by xy, SP = saprophytophagous (on dead vegetal rotting material associated with dead wood debris) (Audisio et al., 2015).

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