

Research article

Submitted: November 13th, 2021 – Accepted: September 20th, 2022 – Published: December 15th, 2022
DOI: 10.13133/2284-4880/724

Ground beetle assemblages in six different forest ecosystems from Tuscany (Central Italy) (Coleoptera: Carabidae)

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Abstract

Forest ecosystems are an important part of the European territory. In 1994 the Regional Administration of Tuscany (Italy) promoted a monitoring program called MON.I.TO (Intensive Monitoring of forest in Toscana) in order to obtain data on the functioning of the forest ecosystem and on its response to possible sources of disturbance in this part of Italy. Although this monitoring program was mostly dedicated to botanical aspects, zoological research has found its proper place within it, and analyzing carabid coenoses provided useful information on the structural and functional characteristics of the forest. This study was performed in six different Tuscan forest ecosystems (Central Italy): 2 beech woodlands, 2 turkey oak woodlands and 2 holm oak woodlands with the aim of broadening the general knowledge of Italian carabid communities and understanding the ecological, adaptive and biogeographical factors influencing their composition in different forest ecosystems. The analysis of the species richness and abundance data was carried out using non-parametric tests (Kruskal-Wallis and PERMANOVA tests) and descriptive statistic methods (n-MDS, SIMPER) applied to 22 different collected species (some of them endemic to the Italian territory) revealing that beech woodlands differed significantly from other forest types. Beech woodlands hosted carabid communities that are extremely sensitive to environmental simplification, showing a prevalence of brachypterous and predator species. In the other forest types, instead, carabid communities were composed of generalist species with high dispersal ability that were prevalent due to the effects of anthropic activities that occurred over time in these territories. Our results highlight the importance of considering community-wide functional implications in landscape ecology studies.

Keywords: biodiversity, carabid beetles, population dynamics, forest ecosystems, species strategies.

Introduction

Forest ecosystems constitute an important part of the European territory: they cover over than 37% of the total area (Vizzarri et al. 2021). Mankind survival is known to depend on the balanced functioning of terrestrial natural ecosystems and forests are an integral part of these mechanisms. Forests constitute a complex vital structure in which different species integrate and interact with each other, playing an important role in maintaining ecological balances, regulating the climate, ensuring water balance and the nutrient cycle, protecting soils, sequestering large quantities of carbon, carrying out a preventive function against the greenhouse effect. They represent an economic resource, possess essential cultural and spiritual values for many human communities that have lived in harmony with the surrounding environment for millennia. Although forests contain a large part of the historical and evolutionary baggage of terrestrial species, over the centuries, humans have shaped and modified natural landscapes for their own

activities, and forest ecosystems have been exploited to extend the areas to be cultivated, for grazing livestock, to collect timber and other resources to be used for industrial and commercial activities. For these reasons, science must study and verify the links among biological diversity, evolution, and functionality of these ecosystems.

Among the animals that live in forest environments, arthropods represent one of the most important components, both for species richness and abundance of individuals. Although their communities have been continuously exposed to a variety of stressors, they play an important role in maintaining ecosystems' quality and health (Wallwork 1983; Menta & Remelli 2020). Classic studies on ground beetle communities have successfully linked the abundance response of single species, life history traits and assemblage structure with different environmental and geographical variables, making these zoocoenoses particularly suitable as environmental bioindicators (Baiocchi et al. 2012). They are, in fact, diverse and abundant (Rainio & Niemelä 2003), well known both taxonomically and ecologically

Table 1 – Site features of the 6 PMP (Monitoring Permanent Plots). More information in Bartolozzi et al. 1996. XY coordinates according to Gauss-Boaga projection (national projection derived from UTM projection – datum Roma 40). More information in Bartolozzi et al. 2002.

	Foresta del Teso	Vallombrosa	Amiata	Uignano	Cala Violina	Colognole
<i>Location</i>	Rombiciaio	Stefaneri	Fontemarchi	Canesticci	Cala Violina	Le Sorgenti
<i>Gauss-Boaga X</i>	1.647.820	1.707.400	1.713.900	1.656.500	1.645.300	1.616.000
<i>Gauss-Boaga Y</i>	4.884.310	4.847.310	4.758.300	4.812.125	4.745.700	4.818.580
<i>Altitudine (m asl)</i>	1350	1170	650	440	5	250
<i>Aspect</i>	W-NW	NE	N-NW	W-NW	W-NW	NE
<i>Slope %</i>	17	10	variable	9	5	variable
<i>Bedrock</i>	Sandstone	Sandstone	Clay	Clay	Sand	Clay + Ophiolitic + Lime
<i>Rainfall (mm)</i>	2090	1324	728	873	637	978
<i>Mean Temp (°C)</i>	9.3	10.1	12.6	12.9	14.7	15.1
<i>Main Species</i>	<i>Fagus sylvatica</i>	<i>Fagus sylvatica</i>	<i>Quercus cerris</i>	<i>Quercus cerris</i>	<i>Quercus ilex</i>	<i>Quercus ilex</i>
<i>Tree cover (%)</i>	100	100	76	80	69	39

(Lövei & Sunderland 1996; Niemelä 1996; Rainio & Niemelä 2003), widespread over vast geographical areas and in all types of habitats (Baiocchi et al. 2012; Lövei & Sunderland 1996) with high environmental fidelity highlighted by the presence of adaptations in morphology, autoecology and feeding behaviors. In addition, they are all closely related with particular habitat types, successional stages and intensity of the disturbance (Baiocchi et al. 2012; Desender 1989; Kleinwächter & Rickfelder 2007; Koivula 2011). Furthermore, they are also economically important, playing, sometimes, a huge biomass transformation action of small phytophages and detritivores (Brandmayr et al. 2005) controlling harmful invertebrates populations (Holland & Luff 2000; Thiele 1977; Hengeveld 1980; Luff 1987; Lövei & Sunderland 1996; Kromp & Paoletti 1999; Kagawa & Maeto 2014). In the world there are about 40,000 species of Carabidae, of which at least 1,700 are present in the Italian territory (Casale et al. 2021).

MON.I.TO. programme

The state of conservation and ecological efficiency of forest ecosystems has raised serious concerns in Europe for decades and where cases of forest decline have been observed, the need to quantify and qualify the real conditions of the forests and follow their evolution in space and time have become challenging and critical issues to act against the forest' ecosystem decline (Bussotti & Grossoni 1994). Over the years, the European Union states have recognized the need to protect forest ecosystems and monitor their health state by promoting actions aimed at sustainable management and protection, realizing that biodiversity conservation can be linked to sustainable forest management that reflects

natural cycles. Starting from this new vision, the European legislation on these issues was, therefore, particularly rich since various regulations have been issued, with programs that contain the idea of a multifunctional approach to forest resources and ecosystem services (Amori et al. 2022). In this respect, many programs are currently underway in Italy (Amori et al. 2022), but a particular community regulation concerning the protection of forests against atmospheric pollution (EEC Reg. 3528/86 and 2157/92, subsequently amended with Reg. 1091/94) was promoted by the Regional Administration of Tuscany in the second half of the 1990s and from which derived the program called MON.I.TO. (Intensive monitoring of Tuscan forests). This program was activated in 1994 with the conviction that any action on forests, in terms of conservation, mitigation or restoration, required the acquisition of reference data on the components, structure, functions and processes of these ecosystems (Bussotti et al. 1995; Ferretti et al. 1993, 1996).

Aims

From this quick overview, it is clear that the study of coenoses can provide indications: a) on the structural and functional characteristics of a particular ecological context in which these communities are embedded; b) on the consequences of the processes that occurred in the past; c) on the response, in terms of resistance and structural resilience, to environmental changes of natural or anthropic origin. Although the MON.I.TO. program was almost exclusively interested in the botanical aspect, this zoological research can find its precise scientific location by proposing: 1) to obtain a general cognitive picture of the carabid fauna present in the examined areas, trying to obtain useful

information capable of expanding the scientific knowledge for this group of arthropods (also providing suitable information in the management of the environments where they live); 2) to compare the responses among diversity, abundance, autecological and chorological characteristics of each species by analyzing the dynamics and strategies that Carabidae populations can implement in the different forest contexts; 3) to understand if the community responses observed in different forest types are congruent with models currently accepted by the scientific community.

Materials and methods

Study areas

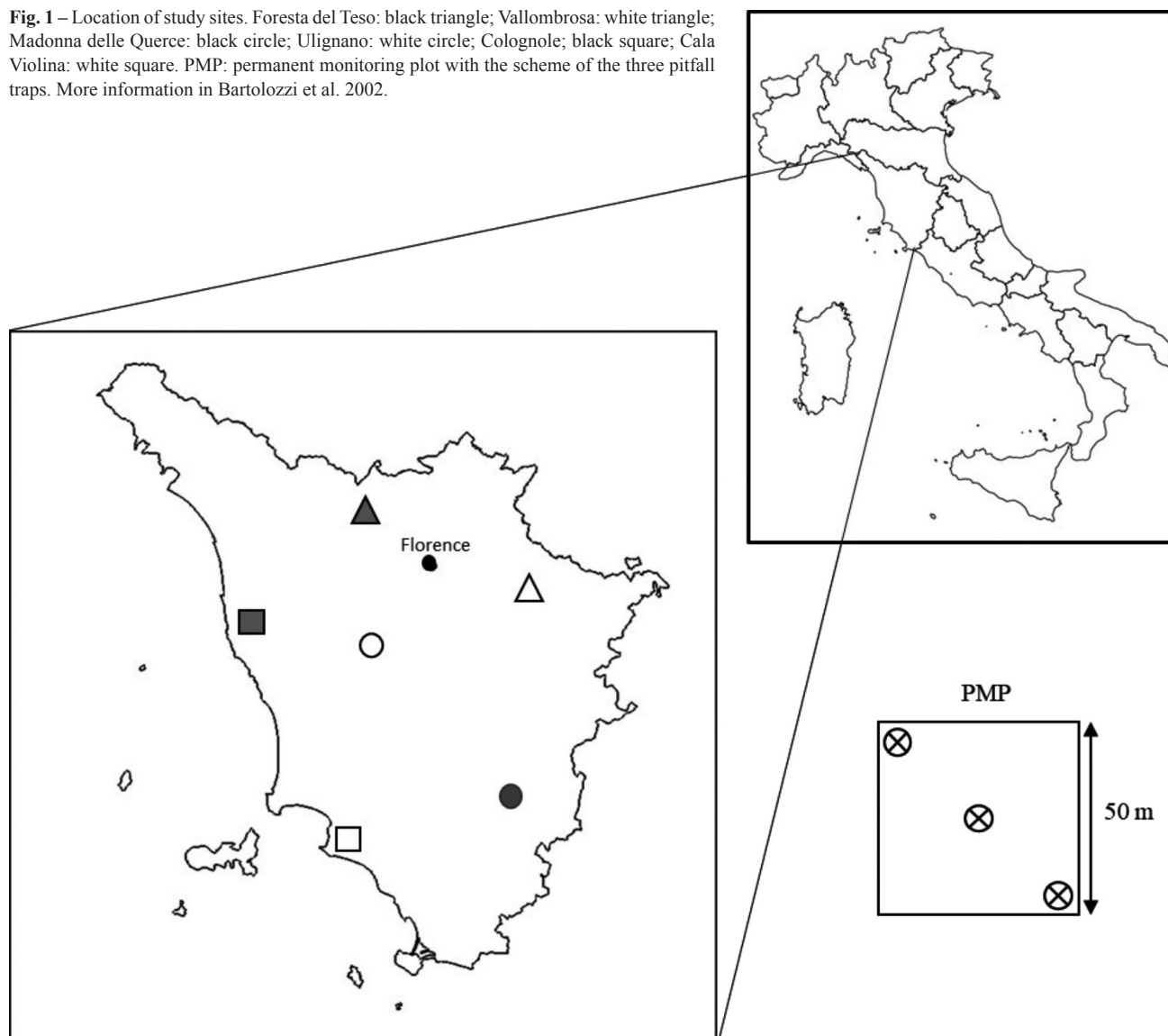
In 1994 the Tuscan Region by launching the MON.I.TO. programme established six 2500 m² (50m x 50m) permanent

monitoring plots (PMPs) in six sites dominated by *Fagus sylvatica*, *Quercus cerris* and *Quercus ilex*, species characterizing the majority of forest vegetation from the Apennine mountains to the Mediterranean coastline (Bartolozzi et al. 2002) (Fig. 1):

- 2 plots in Apennine forests (beech woods): Vallombrosa (Florence Province) and Foresta del Teso (Pistoia Province);
- 2 plots in central Tuscany hilly forests (turkey oak woods): Uignano (Val di Cecina, Pisa Province) and Madonna delle Querce (Amiata mountain, Siena Province);
- 2 plots in Mediterranean woods (holm oak woods): Colognole (Valle Benedetta, Livorno Province) and Cala Violina (Bandite di Scarlino, Grosseto Province).

The plots were chosen so that each pair included two differentiated habitat types, one more xeric (Vallombrosa,

Fig. 1 – Location of study sites. Foresta del Teso: black triangle; Vallombrosa: white triangle; Madonna delle Querce: black circle; Uignano: white circle; Colognole: black square; Cala Violina: white square. PMP: permanent monitoring plot with the scheme of the three pitfall traps. More information in Bartolozzi et al. 2002.



Ulignano and Cala Violina), the other more mesic (Foresta del Teso, Madonna delle Querce and Colognole) (Table 1).

Carabids were sampled using pitfall traps. Although there are intrinsic biases to pitfall trapping which may influence carabid catches (Topping & Sunderland, 1992), standardized pitfall trapping was considered a suitable collection method for comparing patterns of assemblage-wide species traits. This type of trapping, largely used by most Italian carabidologists, allowed us to obtain faunistic data comparable with that collected in similar Italian habitats. At each 2500 m² PMP, three pitfall traps were placed along the diagonal of the area itself. To avoid interference, the distance among the traps was about 20 m (Topping & Sunderland, 1992) (Fig. 1). Eighteen traps were used in the sampling procedure. Each trap consisted of a 550 ml polyethylene beaker (ø 90 mm) filled with 300 ml of a solution of salt and wine vinegar. Traps were covered with a circular plastic roof (ø 200 mm) to prevent excessive rain and litter from reaching them.

Carabid communities were sampled from March 1996 to January 1997, and pitfalls were emptied monthly. Carabid beetles were identified using standard keys (Porta 1923; Jeannel 1941, 1942) and followed the nomenclature in Brandmayr et al. (2005).

Species traits

For each species, we collected information regarding: (a) trophic group, (b) wing development, (c) body size, (e) habitat preference, (f) fundamental chorotype (Table 2).

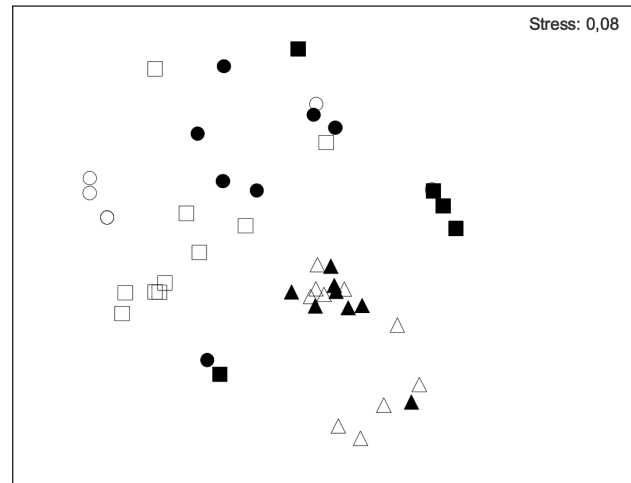


Fig. 2 – n-MDS ordination of mean carabid beetles data ($\log(x+1)$ transformation, Bray-Curtis dissimilarity). Symbols identify the 6 PMPs examined during the search: Foresta del Teso: black triangle; Vallombrosa: white triangle; Madonna delle Querce: black circle; Ulignano: white circle; Colognole: black square; Cala Violina: white square.

Trophic group and wing development were derived from Brandmayr et al. (2005). Information on habitat preference was obtained from Magistretti (1965), Casale et al. (1982) and Brandmayr et al. (2005). Body size categories were established according to Vigna Taglianti et al. (1994). Chorotypes were attributed as defined by Vigna Taglianti et al. (1992, 1999) and Brandmayr et al. (2005).

Data Analysis

Table 2 – Classification of life–history traits. The second column contains a brief description of each life-history trait. The third column lists the name of the variable associated with each life-history trait.

Life-history trait	Description	Response variable
Trophic group		
Traditional predator	Predator species that recognize their prey using mainly olfactory and tactile stimuli	OL
Visual predator	Predator species that recognize their prey mainly using visual stimuli	VP
Wing development		
Macropterous species	Species with fully developed hind wings	M
Brachypterous species	Species with reduced or absent hind wings	B
Wing dimorphic species	Species in which only part of the population is fully winged	D
Body size		
Large size species	Species with body lengths exceeding 12 mm	LAR
Medium size species	Species with body lengths ranging from 6 to 12 mm	MED
Small size species	Species with body lengths shorter than 6 mm	SMA
Habitat preference		
Forest species	Species occurring in mesic habitats	FOR
Thermophilous woodland species	Species occurring in thermophilous deciduous woodland	THERM
Forest generalist species	Species occurring in different forestal types	GENFOR
Open habitat species	Species occurring in meadow, pastures and crops	OPE
Generalist species	Species occurring in both open landscapes and forests	GEN

To quantitatively analyze the diversity of each carabid coenosis, community indices were taken into consideration, such as species richness (S) and, as a measure of abundance, the number of individuals of each collected species (N).

Preliminarily the normality of the data distributions was tested by applying the Kolmogorov and Smirnov test. Unfortunately, Z value applied to both the original and to square root and logarithmic ($\log(x + 1)$) transformed data was always significant ($P < 0.05$), showing a non-normal distribution of the data. Based on this preliminary analysis, only non-parametric statistics techniques were used. To identify statistical differences among carabid coenoses, the Kruskal-Wallis test was applied, through the use of the STATISTICA® package (StatSoft).

The multivariate distances among samples were calculated with the Bray-Curtis dissimilarity index after log transformation of the mean abundance data, and the resulting distance matrix was analyzed by non-metric multidimensional scaling (nMDS) according to Clarke & Warwick (2001). The SIMPER procedure was used to determine which species contribute most to foster the dissimilarity among samples (Clarke & Warwick 2001).

Species composition differences were tested with a permutation-based non-parametric multivariate analysis of variance (PERMANOVA), using “woodland types” and “sites” as factors (Anderson 2005). When significant differences were detected, a multivariate pair-wise a posteriori comparison was performed to highlight significantly different groups (at $p < 0.05$). The Primer 6 program package was used for these analyses (Clarke & Warwick 2001).

Results

We collected 4,636 individuals belonging to 22 different species. From the autoecological point of view, 16 out of 22 species (72.7%) are linked to typical forest environments, both thermophilous and mesophilous, to which ubiquitous entities are associated. Among them, nine were forest species (4,244 individuals), four were forest generalist species (25 individuals), three were thermophilous woodlands species (25 individuals), five were generalist species (330 individuals) and only 1 were open-habitat species (1 individual) (Table 3).

Overall, the collected species can be referred to nine chorological classes that can be grouped into three sets: chorotypes of widely distributed species in the Holarctic region (OLA, SIE, TEM, TUE, EUM), chorotypes of widely distributed species in the European area (EUR, CEU, SEU), and Italian endemisms (END) that represents 27.3% of the collected species (Table 3). *Carabus rossii*, *Platyderus neapolitanus* and *Calathus montivagus* are species widespread over the entire Italian territory, while *Percus passerinii* and *Percus paykullii* are more localized

elements in the Apennine chain. Also, *Cychnus italicus*, subendemic in Italy can be considered a real Apennine element, typical of thermophilous woods (Vigna Taglianti 2009). Analyzing the categories related to feeding behavior, it can be noted that the species found in the study areas are mainly predatory entities belonging to the olfactory-tactile type (OL = 91%). Regarding wing development type, an adaptation strictly connected with the dispersal ability of individuals, the greater group is represented by species with low dispersal power (B = 72.7%).

Individual's body size shows that 50% of the entities are large as compared to 36.4% of entities whose dimensions range between 6 and 12 mm (MED). Only 13.6% is represented by small size species (SMA) (Table 3).

The highest abundance was observed in the Foresta del Teso beech forest (2,526 individuals), whereas the highest species richness was found at Vallombrosa, with 11 different species. In both beech woodlands, the most abundant species was *Nebria tibialis* (3,210 individuals). As for the other sites, nine and eight different taxa were collected respectively in the Monte Amiata turkey-oak woodland and in the Cala Violina holm-oak woodland, with 141 individuals in the first and 178 in the second one, respectively. Very poor carabidocoenoses were found in Ulignano (five species with 10 individuals) and Colognole sites (three species with 12 individuals) (Table 4).

Statistical analysis carried out on the quantitative data highlighted significant differences, both in species richness (S) ($\chi^2 = 68.88$; $p < 0.0001$) and abundance (N) ($\chi^2 = 68.74$; $p < 0.0001$), among the different forest contexts.

The ordination made utilizing non-metric Multidimensional Scaling (n-MDS) on carabid mean abundance data showed how beech forests group together more clearly than other forestal sites (Fig. 2). The latter seems to show a less homogeneous multivariate dispersion which, in the case of Colognole and Ulignano, does not seem to provide certain information.

The PERMANOVA test confirmed the information provided by the n-MDS ordination. The test revealed a significant effect of the factor site ($F = 5.714$; $P < 0.0001$) and woodland types ($F = 11.659$; $P < 0.0001$). The interaction between the tested factors was significant ($F = 9.26$; $p < 0.001$) with beech forests always different from turkey-oak and holm-oak woodlands, which did not show significant differences between them.

The SIMPER procedure shows the lowest mean dissimilarity value (76.54) between the two beech forests, while the highest values (values between 99.13 and 99.9) were found between each beech forest and other woodlands. The most contributing species in determining the internal similarity between beech woodlands was the forest species *N. tibialis* (percentage contribution 43.42%), while the euriecious *Carabus rossii* dominates both the turkey-oak (45.86%) and the holm-oaks (61.51%) woodlands.

Table 3 – Life-history traits of carabid species caught in the study areas. Column 2 reports the chorotype of each species **OLA** = Holarctic; **SIE** = Sibiric-European; **TEM** = Turanic-European-Mediterranean; **TUE** = Turanic-European; **EUR** = European; **CEU** = Central European; **EUM** = European-Mediterranean; **SEU** = S-European; **END** = endemism of Italian territory. List of taxa follows Casale et al. (2021).

Species	Chorotype	Trophic group	Wing development	Body size	Habitat preference
<i>Calosoma sycophanta</i> (Linné, 1758)	OLA	OL	M	LAR	THERM
<i>Carabus rossii</i> Dejean, 1831	END	OL	B	LAR	GEN
<i>Carabus convexus</i> Fabricius, 1775	SIE	OL	B	LAR	THERM
<i>Carabus violaceus picenus</i> A. Villa et G.B Villa, 1838	EUR	OL	B	LAR	GENFOR
<i>Cychrus attenuatus attenuatus</i> (Fabricius, 1792)	CEU	OL	B	LAR	FOR
<i>Cychrus italicus</i> Bonelli, 1810	SEU	OL	B	LAR	GENFOR
<i>Nebria tibialis</i> (Bonelli, 1810)	SEU	OL	B	MED	FOR
<i>Notiophilus biguttatus</i> (Fabricius, 1779)	OLA	VP	D	SMA	FOR
<i>Notiophilus rufipes</i> Curtis, 1829	EUR	VP	D	SMA	FOR
<i>Trechus quadristriatus</i> (Schrank, 1781)	TEM	OL	M	SMA	GEN
<i>Platyderus neapolitanus</i> (Reiche, 1855)	END	OL	B	MED	GENFOR
<i>Calathus fuscipes</i> (Goeze, 1777)	EUM	OL	D	MED	GEN
<i>Calathus montivagus</i> Dejean, 1831	END	OL	B	MED	GEN
<i>Laemostenus acutangulus</i> (Schaufuss, 1862)	END	OL	B	LAR	THERM
<i>Pterostichus apenninus</i> (Dejean, 1831)	SEU	OL	B	MED	FOR
<i>Pterostichus bicolor</i> Aragona, 1830	CEU	OL	B	MED	FOR
<i>Pterostichus micans</i> Heer, 1841	SEU	OL	B	LAR	GEN
<i>Poecilus cursorius</i> (Dejean, 1828)	TUE	OL	M	MED	OPE
<i>Molops ovipennis medius</i> Chaudoir, 1868	SEU	OL	B	MED	FOR
<i>Percus passerinii</i> (Dejean, 1828)	END	OL	B	LAR	FOR
<i>Percus paykulli</i> (P. Rossi, 1792)	END	OL	B	LAR	GENFOR
<i>Abax parallelepipedus</i> (Piller et Mitterpacher, 1783)	EUR	OL	B	LAR	FOR

Discussion

Measuring biodiversity means understanding population changes to obtain an analysis of the environmental status and to manage conservation plans (Cameron & Leather, 2012). For many decades, carabid beetles have been one of the favorite study subjects of researchers who wanted to compare different habitats, since for each variation there are differences in the composition and abundance of species within the communities (Halme & Niemelä, 1993; Davies & Margules 1998; Abildsnes & Tømmeros 2000; Holland & Luff 2000; Rainio & Niemelä 2003). From our results, it emerges that collected communities, although poor in some environmental contexts show a physiognomy congruent with the analyzed habitats. It is possible to state that, apart from few euricicous species that can be found in any environmental context, such as *Carabus rossii*, *Trechus quadristriatus*, *Calathus fuscipes*, *C. montivagus*, most of the detected species belong to a temperate and thermophilous forest fauna (in this case holm-oak and turkey-oak woods), such as *Carabus convexus*, *C. violaceus*, *Platyderus neapolitanus*. Mesophilous entities, such

as *Nebria tibialis*, *Pterostichus bicolor*, *Molops ovipennis medius*, are instead typical in higher altitude forest areas. From the biogeographical point of view, it emerged that current geographical distribution of species reflects both historical processes and recent ecological constraints. In particular, a large stock of species colonized the Italian territory during Pleistocene glaciations favoring the dispersal of mesophilous species from northern regions to southern areas (Fattorini & Vigna Taglianti 2015). The sequence of temperate interglacial (anatermic) and glacial (catatermic) climatic phases, which followed one another in the Mediterranean basin, have shaped arthropods communities as evidenced by the simultaneous presence of thermophilous elements, widespread in central-southern Europe, and mesophilous ones, often found at high altitude or in relict sites (Brandmayr et al. 2005). In this research these faunistic contingents, which are mainly characterized by elements belonging to the subfamilies Carabinae, Nebriinae and Pterostichinae, saw the presence of *Carabus violaceus*, *Cychrus attenuatus*, *Nebria tibialis*, *Pterostichus micans*, *P. bicolor*, *Abax parallelepipedus*, together with elements exclusive to the entire Italian territory such as

Carabus rossii, *Platyderus neapolitanus* and *Calathus montivagus*, with *Percus passerinii* and *P. paykulli* which have a much more localized distribution in the northern part of the Apennine chain. Noteworthy is the recent discovery of *P. passerinii* in a relict beech forest in southern Tuscany. This discovery aims at suggesting that, during the last glacial period, some mesophilous carabid species must have had a much wider distribution and occurred at lower altitudes than current ones (Migliorini et al. 2002).

The analysis of the quantitative data and the sites ordination carried out with the n-MDS showed how only beech woods are able to clearly group, showing statistical differences from other forest sites. Although a great number of factors can drive the presence of a taxon in a certain habitat, the presence of morphological adaptations and feeding behaviors in each species can represent a valid survey tool for assessing the degree of environmental integrity.

The data collected in the two beech forests seem to follow what is known for this environment that, in Italy, occupies a large part of the Apennine chain, constituting a highly biodiverse ecosystem that has “historically” recruited mountain elements rich in brachypterous populations. These latter, in geographic and environmental isolation, easily tend to allopatric speciation and, therefore,

to the formation of endemic species. The importance of the loss or reduction of functional wings typical in stable forest communities seems to be linked to the fact that these species can only survive in sufficiently large environments characterized by a low degree of anthropogenic and/or natural disturbance (Brandmayr 1983; Lövei & Sunderland 1996; Kotze et al. 2003; Zalewski & Ulrich 2006; Gobbi & Fontaneto 2008). It is now established that large-size species, with predatory feeding behavior, are more sensitive (stenotopic) to environment simplification with respect to smaller ones. They tend to reduce their wings in stable environments so that the percentage of micropterous species increases with the progress of the ecological succession and decrease with the increase of the disturbance and habitat fragmentation, impoverishing the habitat of wingless species and enriching it with smaller and generalist (eurytopic) winged species with greater dispersal capacity (Brandmayr et al. 2005; Eversham et al. 1996; Gobbi & Fontaneto 2008; Koivula 2011). From a conservation point of view, therefore, beech forest carabid beetles communities represent a valuable element, both for their adaptive abilities within a more stable environment and for their consequent scarce ability to react to environmental transformations.

Table 4 – Carabidae beetles (and their total abundances) collected in six different forest habitats during the entire sampling period. List of taxa follows Casale et al. (2021).

	Foresta del Teso	Vallombrosa	Amiata	Uignano	Cala Violina	Colognole
<i>Calosoma sycophanta</i> (Linné, 1758)					10	
<i>Carabus rossii</i> Dejean, 1831	1			6	142	
<i>Carabus convexus</i> Fabricius 1775	1		7	1	5	
<i>Carabus violaceus picenus</i> A.Villa et G.B Villa, 1838			1			
<i>Cychrus attenuatus attenuatus</i> (Fabricius, 1792)	2					
<i>Cychrus italicus</i> Bonelli, 1810	8	10	1	1		9
<i>Nebria tibialis</i> (Bonelli, 1810)	1755	1455				
<i>Notiophilus biguttatus</i> (Fabricius, 1779)		8			1	
<i>Notiophilus rufipes</i> Curtis, 1829		2				
<i>Trechus quadristriatus</i> (Schränk, 1781)		5	5	1		1
<i>Platyderus neapolitanus</i> (Reiche, 1855)		1			4	
<i>Calathus fuscipes</i> (Goeze, 1777)			5	1		
<i>Calathus montivagus</i> Dejean, 1831			93		9	
<i>Laemostenus acutangulus</i> (Schaufuss, 1862)			1			
<i>Pterostichus apenninus</i> (Dejean, 1831)	38					
<i>Pterostichus bicolor</i> Aragona, 1830	692	202				
<i>Pterostichus micans</i> Heer, 1841	2	24	27		6	2
<i>Poecilus cursorius</i> (Dejean, 1828)			1			
<i>Molops ovipennis medius</i> Chaudoir, 1868	23	13				
<i>Percus passerinii</i> (Dejean, 1828)		21				
<i>Percus paykulli</i> (P. Rossi, 1792)					1	
<i>Abax parallelepipedus</i> (Piller et Mitterpacher, 1783)	4	28				

The hilly and submontane belts are those that have historically suffered the most prolonged and intense anthropic impact on the entire Italian territory. Since prehistoric times, man has settled in these favorable areas, practicing agriculture and livestock, shaping the natural landscape and making it extremely heterogeneous. Coppice management and the more or less intense grazing have modified original forest structures by replacing them with intricate mosaics of more or less stable and persistent secondary ecosystems (De Dominicis 1993). This played an important role regarding species composition as highlighted, in this case, by a generalized impoverishment of the fauna which, over time, has seen an increase in the presence of eurieciotic and xerothermophilous entities (Sjödin et al. 2008). To confirm this statement, data collected in the Ulignano turkey-oak wood showed one of the lowest values of both species richness (five eurytopic taxa) and abundance (only nine individuals were collected during the entire sampling period). This fact is probably to be attributed to the massive presence of grazing cattle in the proximity of the sampling site, representing a strong disturbance factor able to drive a massive dispersion of most of the taxa that could potentially be present in the entire area. Concerning the Amiata mountain turkey-oak wood, an intermediate faunistic structure, if compared to the other sites, results evident. Generalists *Calathus montivagus*, *C. fuscipes*, and *Pterostichus micans*, widely diffused species on the Italian territory, have been found in association with *Carabus convexus*, *C. violaceus*, *Cychrus italicus*, taxa whose presence is typical in open woodlands. Once again, this simplified composition can be traced back to historically recent changes linked to anthropic actions that have taken place along the slopes of Monte Amiata. In fact, Dainelli (1910) at the beginning of the last century, regretted that he was no longer able to admire the “Amiata highlands” of which only “severed trunks” remained as a result of the wood cutting made to satisfy the needs of the nearby mines and the intense afforestation of conifers which were replacing the original plant associations (De Dominicis 1993).

The very low number of both species and individuals recorded in the Colognole site (holm-oak wood), an area close to the sea although located on the internal side of a coastal hill chain, highlights a trend similar to the continental site of Ulignano (turkey-oak wood). In this site, the presence of very few and not very abundant generalist species (*Cychrus italicus*, *Trechus quadristriatus*, *Pterostichus micans*) confirms the information obtained from the scientific literature from which it is deduced that the holm-oak woods represent unfavorable environments for soil arthropods (Brandmayr et al. 1983). The cause seems to be attributable to the fact that the Mediterranean sclerophyll forests, widespread along the Tuscan coastal belt, represent a relatively recent biome (Pizzolotto et al. 2005) which, after the slow drying process of the Mediterranean basin during the Miocene, has led to the current climatic

configuration characterized, after the Pleistocene glacial phases, by a strong climatic seasonality (Brandmayr et al. 1983, 2005; De Dominicis, 1993).

The second coastal holm-oak wood (Cala Violina) has expressed a more balanced carabid coenosis than the previous one, certainly more typical for these environments, as confirmed by the presence of generalist and thermophilous wood species, such as *Calosoma sycophanta*, *Carabus rossii*, *C. convexus*, *Calathus montivagus*, *Pterostichus micans*, *Platyderus neapolitanus*, *Percus paykulli*, that often show the typical phenological trait of Mediterranean coastal areas with a second activity peak in winter (Brandmayr et al. 2005). The discovery of a single specimen of *Notiophilus biguttatus*, a typical montane forest element, in this coastal station can only be confirmed by further samplings. At the moment no certain deductions can be made about its presence other than the hypothesis of a casual introduction and the consolidation of a small localized population.

We can state that differences between the two holm-oaks woodlands can be attributed to differences both in the geological substrate and in the effects of past anthropic activities that occurred in the two coastal areas. Colognole area is situated on serpentine soils and although little information on edaphic arthropod communities in ultramafic soils is present in the scientific literature, serpentinites represent a well-known example of a stressful environment. These kinds of soil are often shallow and deficient in nutrients, with low Ca/Mg ratio and relatively high concentrations of potentially toxic metals, such as Ni, Cr and Co (Chiarucci 1996) making them unfavorable to plant and soil fauna life (Visiolia et al. 2019). Furthermore, Colognole site appeared as a more immature habitat which, together with holm oaks, sporadic fruit plants, residual of a recent agricultural activity, coexisted with parcels of territory reforested with *Pinus nigra*. On the other hand, Cala Violina, characterized by sandy soils, doesn't seem to have suffered particularly heavy anthropic impact.

Conclusions

Although it is known that the spatial distribution of carabid beetles is varying over time as a function of climate change with effects on their altitudinal and geographic distribution, especially on a large spatial scale (Brandmayr et al. 2013), the data presented in this research, collected on a smaller spatial scale in the mid-90s within a wide altitudinal range, don't lose their scientific value by confirming that beech forests are the most stable, rich in trophic resources environments, able to create optimal conditions for generating different ecological niches and maintaining rich and diverse arthropod fauna.

The other investigated ecosystems are certainly more unstable and younger because, as in the case of the turkey-oak woodlands, this type of environment, in Tuscany,

has been historically exploited by man for both grazing and wood harvesting. These factors heavily affect the structure of these zoocoenoses which tends to be composed of euryecious elements with high dispersal capacities. As for the holm-oaks woodlands, the carabid cenoses of Colognole was likely going through, together with the whole ecosystem, a transition period which may evolve to a more mature condition. A more stable condition has probably been already reached by the holm oak of Cala Violina, where carabid beetle communities seem to express a more typical aspect for these coastal ecosystems.

Conservationists and managers of natural environments generally agree that the protection of species diversity is a priority on a global and national scale. Although at smaller spatial scales richness and species identities have often been considered a negligible conservation parameter, carabids, thanks to their adaptive responses, are able to describe any environmental situation confirming their bioindication power even at smaller spatial scales (Koivula 2011).

This study made it possible to identify a large number of Italian endemisms embedded in communities of ground beetles where brachypterous entities seem sensitive and vulnerable to small scale habitat change. This suggests that preserving areas in the landscape that support greater biodiversity or recovering the most disturbed ones, will preserve those species potentially more susceptible to habitat loss and fragmentation.

Acknowledgments – We thank Prof. De Dominicis for authorizing access to the permanent monitoring plots to carry out our faunistic samplings.

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