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Stand maturity affects positively ground-dwelling arthropods in a protected beech forest

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Key message: Forest maturity benefits biodiversity by providing positive effects on key arthropod assemblages such as spider and ground beetles, which play a fundamental role in the ecosystem.

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Contributions of individual authors

Marco ISAIA designed the experiment, coordinated the research project, wrote the manuscript, participated to the field work and supervised spider identification. Mauro PASCHETTA wrote the manuscript, contributed to fieldwork, to spider identification and performed the statistical analysis in R. Mauro GOBBI gave a substantial contribution to the writings, especially in the discussion on Carabids. Marzio ZAPPAROLI identified Chilopods and contributed to the writings of the paper by adding important insights about Chilopods. Alberto CHIARLE helped in the fieldwork, sorted the material and identified the spiders. Augusto VIGNA TAGLIANTI identified Carabids and supervised the final version of the manuscript.

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Abstract

Context: Sustainable forest management is a widely held international goal and more knowledge is needed on invertebrate assemblages, essential to the ecological functioning of forest ecosystems.

Aims: We aim at evaluating the effects of microsite conditions on spider, centipede and ground beetle assemblages living in an unmanaged protected beech forest within the Natural Park of Alpi Marittime (SW-Alps, Italy). In view of our results, we provide insights on the successional pathways of the focal assemblages in relation to future management of the forest, recommended by the local authorities for conservation purposes.

Methods: We placed 50 pitfall traps along four transects crossing the forest and emptied them monthly, from July to October 2011. We characterized the four arthropod assemblages in terms of abundance, species richness, diversity and biomass and related them to leaf cover, rock cover, wood debris cover, litter depth, number of trees, mean tree size and light conditions at ground level using generalized linear mixed models (GLMM) and canonical correspondence analysis (CCA).

Results: Thirty-one species of spiders (1,212 individuals), twelve of centipedes (262 individuals) and eleven of ground beetles (2,177 individuals) were collected. In all groups, mature-forest species highly dominated the samples. Tree size proved to be one of the most important parameters conditioning the assemblages, in particular spiders and ground beetles. A minor effect of light conditions and ground cover (presence of wood debris) was also detected.

Conclusions: In view of our results, the recent guidelines for the management of the forest seem in accordance with an effective conservation of the forest arthropod assemblages. Interventions aimed at stabilizing and renovating critical areas within the forest go along with a progressive amelioration of the forest arthropod community. With respect to the maintenance of a large degree of arthropod diversity, stand thinning may not be the most effective management, and reaching a more mature stage might be of interest.

Keywords: Forest ecology; Araneae; Chilopoda; Carabidae

1. Introduction

Forest management embodies complex ecological issues, having profound effects on processes and biological assemblages in forest ecosystems (Christensen & Emborg 1996). According to different practices, like harvesting, clear cutting and coppicing, forest management may affect habitat quality and quantity and consequently, biodiversity. As sustainable forest management is a widely held international goal (Pearce & Venier 2006), more knowledge of the animal communities is needed, especially the one that are essential to the ecological functioning of the ecosystems.

Specifically, spiders (Arachnida: Araneae), centipedes (Myriapoda: Chilopoda) and ground beetles (Coleoptera: Carabidae) proved to be effective ecological indicators in forest ecosystems (Paradis & Work 2011, Pearce & Venier 2006). In particular, they share an important trophic position, regulating populations of forest-floor invertebrates and serving as prey for many vertebrates. Moreover spiders, centipedes and ground beetles constitute the most conspicuous groups of predator arthropods in the forest litter environment, providing an important ecosystem service (Jouquet et al 2006, Purchart et al 2013). Understanding how these assemblages change through time can help in the management of forest ecosystems in a more appropriate (natural) manner.

Beech forests characterize the landscapes of the montane level of the Italian Alps. Since the Middle Ages, these resources have been managed accordingly to the use of timber (i.e., firewood, charcoal or timber for building and furniture), determining variations in habitat conditions at the ground level. Due to the development of other low cost energy sources and the depopulation of mountain areas, from the 1960s, many beech coppices have been progressively abandoned and converted to high forests. The major process of conversion is the reduction of the stand density, with repeated thinning of the shoots, promoting the growth of the best shoots and reducing the resprouts.

According to EU Council Directive 92/43/EEC (Habitats Directive), nowadays alpine beech forests are regarded as habitat of communitarian importance, whose protection requires the designation of special areas of conservation.

Most of the studies concerning the influence of forest management on arthropod assemblages focused on the effects of clear cutting (Paradis & Work 2011), fire (Buddle et al 2000 and references herein), successional phase of the forest (Christensen & Emborg 1996, Grgič & Kos 2005) and forest fragmentation (Pajunen et al 1995). Pearce & Venier (2006) reviewed the use of spiders and ground beetles as bioindicators in different forest managements, highlighting that both in ground beetles and spiders, clear cutting induces changes in the composition of the community, such as shifts in the assemblage dominance from forest to open-habitat species (Buddle et al 2000).

Despite forest age proved to have considerable importance for biodiversity (Meier et al 2005), the effects of stand maturity on arthropod assemblages have been rarely investigated. Moreover, papers dealing simultaneously with community development dynamics of different taxonomical groups at the same time and on the same site are scarce and a multi taxa approach is particularly recommended (Tropék et al 2008).

In this study we hypothesise that species richness, diversity, abundance and biomass of epigeic arthropod predator assemblages (namely spiders, centipedes and ground beetles) change with stand maturity in relation to the microsite variations (e.g. changes in ground cover, amount of litter and light conditions at ground level). Specifically we target arthropod predator assemblages living in a protected beech forest within the Natural Park of Alpi Marittime (SW-Alps, Italy). Moreover, in view of the future management of the forest, we aim at providing insights on the changes of the focal assemblages in relation to the environmental modifications induced by thinning and ageing advised by the local managing authority in one portion of the study area that was historically subjected to coppicing.

2. Materials and methods

2.1 Study area

The study was carried out in summer 2011 at the protected beech forest of Palanfrè (approximately 9 hectares), within the Natural Park of Alpi Marittime (NW-Italy, SW-Alps, Piedmont Region, Province of Cuneo) (Fig. 1). Given its peculiar biological diversity, the alpine district in which the

park is located (Maritime Alps) has been defined as a key area to understand the dynamics that shaped the fauna of the Italian peninsula as well as that of Western European one (Minelli et al 2007). In view of the extraordinary biological diversity, the Park hosted the first European All Taxa Biodiversity Inventory (<http://www.atbi.eu/mercantour-marittime>), in which the present work and other ecological studies were framed (Paschetta et al 2013).

The beech forest is located on a slope facing NE and ranging from 1,400 to 1,700 m a.s.l. The Palanfrè forest is a Special Area of Conservation (SAC), classified as “Medio-European subalpine beech woods with *Acer* and *Rumex arifolius*” according to EU’s Habitat Directive. The exploitation of the forest started at the beginning of seventeenth century, with the first human settlements in the area. However, according to its defensive function from avalanches and landslides, since the mid-1,700s the northern portion of the forest has been protected and not logged (Regione Autonoma Valle d’Aosta and Regione Piemonte 2006) and only small interventions aiming at stabilizing the stand have occurred. This long undisturbed period has determined unique example of natural development of the forest community in Italy. On the contrary, the southeastern part of the forest has been subjected to coppicing until 1976, when silvicultural practices were totally abandoned (Cati Caballo, Alpi Marittime Natural Park, pers. comm.). Hence, we can divide the forest in two main parts (approximately 4.5 hectares each) according to historical management: an unmanaged reference part shaped as a high forest (RS), with sparse, large and even-aged stands, and an uneven transitional stage resulting from historical coppicing (CO), with dense and thinner stands (Fig. 1). The reproductive origin of the trees of the forest mostly derives from seeds (80%) and only a small part (20%) from selection of coppice shoots (Cati Caballo, Alpi Marittime Natural Park, pers. comm.).

Under the advice of the Natural Park of Alpi Marittime and the Regional Administration of Piemonte, recent guidelines for the management of the protected forest have been published (Regione Autonoma Valle d’Aosta and Regione Piemonte 2006). The work underlines problems in terms of stability and renovation, with interventions aiming at the removal of unsteady trees and at promoting renovation or affirmation of new units, especially where the tree population is more dense and mono-layered (i. e. in the former coppice). In particular, for the area formerly subjected

to coppice, ageing and thinning are advised, aiming to level this part of the forest to the unmanaged reference stand.

2.2 Sampling design

We placed 50 pitfall traps along 4 transects crossing both the unmanaged reference stand (RS, 25 traps) and the former coppice (CO, 25 traps). Traps were placed at a minimum distance of 25 m one from each other thus ensuring spatial independence for arthropods (Digweed et al 1995). Transects were placed at 1,500 (8 traps), 1,550 (17 traps), 1,600 (16 traps), 1,650 (9 traps) m a.s.l. (Fig. 1) at the end of July 2011 and emptied every month until mid-October (3 periods: 21 July – 11 August; 11 August – 9 September; 9 September – 13 October), for a total of 150 samples (50 traps x 3 periods). Each trap consisted of a plastic glass of 10 cm in mouth diameter and 12 cm deep. We filled traps with 50 ml of a 50% mixture of water and ethylene glycol. We identified spiders, centipedes and ground beetles at species level whenever possible. We considered only adult specimens in the analysis. Nomenclature follows Platnick (2014) for spiders, Minelli et al (2006) for centipedes and Vigna Taglianti (2004) for ground beetles.

At each replacement of trap, we measured seven environmental variables in circular areas of 2 m diameter (centered on the trap): (1) leaf cover (LEAVES), (2) rock cover (ROCK), (3) wood debris cover (including visible and not highly decomposed wood, WOOD) (all estimated by eye and measured as percentage of ground coverage). We also measured (4) the mean depth of the litter (LITT) (in centimeters, measured with a measurement stick). Moreover, we measured (5) number (i.e. tree density, N_TREES) and (6) mean size of the trees at 1 m height (TREE_SIZE) in a radius of 5 m centered on the trap. Considering that the forest is almost entirely monospecific in terms of tree species, only beech were measured. Furthermore we measured (7) light conditions at ground level (LUM) by taking a picture at ground level, placing the camera above the trap, lens facing upwards. We took all pictures under uniform sky conditions in a single day (21 Aug 2011), from 11 AM to 12 AM. Pictures were processed with the freeware ImageJ (version 1.47), according to the procedure described in Pueschel et al (2012) in order to express light conditions at ground level as a percentage of white pixels in the picture.

3. Data analysis

3.1 Habitat characterization

We identified the former coppice (CO) and the reference stand (RS) directly in the field, in collaboration with forestry experts and on the base of available maps. In order to achieve a better characterization of the two portions of the forest and provide arguments for the discussion on the future management, we performed a Wilcoxon signed-rank test to detect which of the seven registered variables showed significant differences between the two parts. For habitat characterization we combined the data using the mean values recorded at the 3 periods for each environmental variable (= 50 mean observations). The test was performed in R environment (via MASS package, Venables & Ripley 2002).

3.2 Effects of microsite variations on arthropod assemblages

In all analyses evaluating the effects of the microsite variations on the focal taxa, we used replicates as basic sample unit (true replicates of within-stand variation). For each replicate we computed abundance (N), species richness (S) and diversity (Shannon index, H) of spiders, centipedes and ground beetles.

We used body size as proxy for biomass (Sage 1982) (BMS). Specifically, for spiders and ground beetles we computed average body length (spiders: from clypeus to spinnerets in mm; ground beetles: from clypeus to the posterior margin of the elytra in mm). As far as we are aware, biomass in centipedes have rarely been evaluated in ecological studies. Considering that body length may vary due to the properties of the metameric segments of the body, we chose maximum body width as proxy for biomass. Moreover, Spearman's rank order correlation revealed collinearity between body width and body length (Spearman's $\rho=0.645$; $p<0.05$).

For each replicate, we weighted the value (body length for spiders and carabids and body width for centipedes) according to abundance of the species. Data on body size were gathered from specialist works.

We related the biological parameters referring to each assemblage to the registered explanatory variables via General Linear Mixed Models (GLMMs, Zuur et al 2009). Data exploration revealed collinearity between explanatory variables (i.e. the existence of correlation between covariates). If collinearity is ignored, one is likely to end up with a confusing statistical analysis in which nothing is significant, but where dropping one covariate can make the others significant, or even change the sign of estimated parameters (Zuur et al 2010). The easiest way to solve collinearity is by dropping collinear explanatory variables. The dropping of a certain variable rather than one other is based on common sense or biological knowledge (Zuur et al 2010). Given our focus on stand maturity, we have chosen to retain tree size (TREE_SIZE) and exclude tree density (N_TREES) due to collinearity between the two variables. The significance of the relationships was tested via generalized linear mixed models (GLMMs, Zuur et al 2009) in R environment (R Development Core Team 2012). Generalized models were used to deal with the lack in normality of dependent variables. The mixed procedure allowed us to include the temporal variable (“period”) as random factor in order to deal with the temporal dependence of the replicates. Rather than to test for its direct effect on the dependent variable, the inclusion of the random factor accounts for the variation that the temporal variable (sampling period) introduced in our sample.

The resulting model was:

$$\text{Eq. (1) } y \sim \text{environmental variables} + (1|\text{period})$$

where y = one of N, S, H, BMS; environmental variables = WOOD, ROCK, LEAVES, LUM, LITT, TREE_SIZE (fixed effects). The random part of the model (1|period) includes the effect of the temporal grouping variable (“period”).

For abundance and richness data (i.e. count data) we assumed a Poisson distribution and tested for overdispersion prior to model fitting via qcc R package (Scrucca 2004). We evaluated the overdispersion by means of the dispersion parameter “ ϕ ”, based on the chi-square approximation of the residual deviance. If there is overdispersion, the $D\phi$ is Chi-square distributed with $n-p$ degrees of freedom and this leads to $\phi = D/n-p$. If this ratio is about 1 then we can assume there is no overdispersion and the Poisson distribution can be applied. In case of overdispersion, we fit GLMMs assuming a negative binomial distribution, where appropriate.

For Shannon diversity and biomass we assumed a zero-inflated Gaussian distribution. We fitted the regression models via the glmmADMB R package version 0.6.4 (Fournier et al 2012).

Given the explorative nature of our study (no “a priori” hypothesis on the effect of the different variables on the dependent variable), we used a multiple model testing approach (Zuur et al 2009). The best fitting model was obtained with a stepwise selection procedure (backward elimination), according to the Akaike information criterion. GlmmADMB R package was also used in this case.

3.3 Dominant species identity

We examined the relationships between dominant species of the three focal assemblages and environmental factors using canonical correspondence analysis (CCA). We selected only the most abundant species of the dataset: *Coelotes osellai*, *Tenuiphantes tenebricola*, *Harpactocrates drassoides* and *Histoipona leonardo* for spiders; *Aptinus alpinus*, *Cychrus attenuatus*, *Pterostichus bicolor* and *P. funestes* for carabids; *Eupolybotrus longicornis* for centipedes. The sum of the individuals of these nine species constitutes 90% of the total abundance of the specimens collected during the samplings. The significance of the Axes 1 and 2 was evaluated with a Monte Carlo test with 1,000 permutations. Ordinations were performed using PC-ORD software (version 6; McCune and Mefford 2011). The underlying model in CCA assumes that species abundances are unimodally distributed along an environmental gradient. A set of species is directly related to a set of environmental variables and an ordination diagram is produced by detecting patterns of variation in assemblage composition that can be best explained by the environmental variables. Environmental variables are represented as lines irradiating from the centroid of the ordination: the longer the environmental line, the stronger the relationship of that variable with the community. The position of a certain species relative to the environmental lines indicates the relationship between species and the environmental variables. If we run perpendiculars from each species point to the environmental line, we can see the approximate ranking of species-response curves to that environmental variable and whether a species has a higher-than-average or lower-than-average optimum on that environmental variable (McCune et al 2002).

4. Results

4.1 Habitat characterization

The Wilcoxon signed-rank test detected several significant differences between the two parts of the forest (the former coppice and the reference stand) in terms of habitat variables. Significant differences emerged in terms of percentage of wood debris cover on the ground (higher in the former coppice; WOOD: $W=413$; $p<0.01$), tree density (higher in former coppice; N_TREES: $W=625$; $p<0.05$) and tree size (higher in the reference stand; TREE_SIZE: $W=2$; $p<0.05$). For leaf cover (LEAVES), rock cover (ROCK), mean depth of the litter (LITT) and light conditions (LUM) no significant trends were detected.

4.2 Spiders

We collected 31 species of spiders (1,212 individuals) belonging to 9 families (Agelenidae, Amaurobiidae, Cybaeidae, Dysderidae, Gnaphosidae, Linyphiidae, Lycosidae, Pimoidae and Salticidae) (Appendix 1). A number of juveniles (372) could not be identified at species level and they were excluded from the analysis. For spiders, the final dataset was then composed of 840 individuals. The results showed that only spider abundance increased with increasing tree size (Tab. 1).

4.3 Centipedes

We collected 12 species of centipedes (262 individuals) belonging to 4 families (Lithobiidae, Cryptopidae, Geophilidae, Linotaeniidae) (Appendix 2). A number of juveniles (3) could not be identified at species level, so they were excluded from the analysis. The final dataset was composed by 259 individuals.

Centipede biomass decreased with increasing tree size and light conditions at ground level (Tab. 1).

4.4 Ground beetles

We collected 11 species of ground beetles (2,177 individuals) belonging to 5 subfamilies (Brachininae, Carabinae, Pterostichinae, Harpalinae, Platyninae) (Appendix 3).

Species richness, diversity and abundance of ground beetles increased with increasing tree size.

Ground beetle biomass increased with the decreasing woody debris cover (Tab. 1).

3.3 Dominant species identity

Axes 1 and 2 evaluated with a Monte Carlo test with 1,000 permutations were significant ($p < 0.01$).

Fig. 2 shows the ordination of species derived from the species matrix (WA scores). The first two axes of ordination are shown because they explained most of the variance (7.8%). Intraspecific correlations (Ter Braak 1986) of environmental variables indicate that leaf cover, tree size and mean depth of the litter were the main environmental variable influencing the ordination for the Axis 1 (-0.656; -0.637 and -0.562 respectively). Tree density and wood debris cover (0.638 and 0.584, respectively) mostly influenced Axis 2 (Tab. 2).

The approximate ranking of the centers of the distributions of species along the variables (Fig. 2) suggests that the increase in the tree size (which was higher in the reference stand) foster the presence of *Coelotes osellai*, *Tenuiphantes tenebricola* and *Pterostichus bicolor*. On the other hand, *Histopona leonardoii*, *Cychrus attenuatus* and *Aptinus alpinus* were associated with a higher wood debris cover on the ground, which was higher in the former coppice. *Harpactocrates drassoides* was associated with deeper litter. *Eupolybotrus longicornis* and *Pterostichus funestes* were mainly associated with low leaf cover on the ground.

5. Discussion

5.1 Spiders

According to Entling et al (2007), microsite conditions at ground level strongly influence the composition of spider assemblages. In our case study, tree size (which generally reflects stand maturity) was the only parameter affecting significantly spider assemblages. However, the relative homogeneity of the ground level in the study area does not allow the detection of any trend. As

demonstrated by the habitat characterization, the conditions at ground level within the forest did not vary much.

According to the sampling method used, the assemblage was dominated by litter ground dwelling spiders, for which microsites with higher tree size provides conditions that are more favorable. As highlighted by the CCA analysis, the reference stand (with bigger trees) resulted particularly suitable for the SW Alpine endemic *Coelotes osellai* and for the litter specialist *Tenuiphantes tenebricola* (see Fig. 2). Accordingly, the higher structural complexity of older stands plays a primary role for the survival of habitat specialists (Paradis & Work 2011).

5.2 Centipedes

Even if certain groups of mature-forest species of centipedes proved to be sensitive to environmental variations (i.e. changes associated with urbanization, Lesniewska et al 2008), we did not observe it to affect centipedes, except for biomass. The lack of significant results have to be primarily interpreted in view of the sampling method we used, considering that pitfall traps mostly capture epigeic species (e.g., belonging to *Eupolybothrus*, *Lithobius*, *Cryptops*, *Strigamia*) (Grgič & Kos 2009). Moreover, we did not collect edaphic species (mainly Geophilomorpha). Our analysis showed that epigeic centipedes were larger in the more shaded portions of the forest (lower light conditions) and in microsites with lower tree size (more likely younger trees). We relate this trend to the availability of trophic resources, considering that these conditions presumably favor the presence of potential preys (springtails, earthworms, etc.) for epigeic centipedes (Grgič & Kos 2005).

5.3 Ground beetles

Similarly to spiders, litter dwelling ground beetles dominated the samples. The absence of open habitat species or termo-xerophilous ones suggests that the studied forest maintains conditions that mainly favor species associated with closed tree canopy. The significant positive relationship of abundance, species richness and diversity with tree size confirms the suitability of the reference stand for mature-forest species. This result is in accordance with Taboada et al (2010) who found a

positive correlation of species richness - or diversity - and tree size (trunk and crown perimeter).

This positive correlation can be explained assuming that trunk and crown perimeter affect leaf litter depth, microclimate and soil variables which are factors driving the distribution of mature-forest species (Fountain-Jones et al *in press*).

In our case, ground beetles biomass decreased with an increase of wood debris on the ground. Although a direct relationship is hardly explicable, the stability of the reference stand (with lower wood debris ground cover), is probably the most important factor in sustaining populations with long larval development, which are generally large sized species (Blake et al 1994, Gobbi et al 2007). In addition, according to Gobbi and Fontaneto (2008) assemblages with large individuals and low dispersal ability power are generally most abundant in old and stable forests. Accordingly, CCA associates *Pterostichus bicolor* (an endemic medium sized species according to Cole et al 2002) with microsites with low wood debris which also characterize the reference stand.

5.4 Management

The reference stand and the former coppice differs in terms of several habitat variables that proved to affect the arthropod assemblages. Specifically, the variables conditioning the assemblages and differing in the two parts of the forest were the tree density (i.e. the number of the trees), the tree size (a proxy for stand maturity), and the wood debris cover on the ground.

On a long-term scale, thinning will generally increase tree size due to decreasing competition among the remaining trees and may indirectly promote the general abundance of mature-forest species of arthropods. On the other hand, on the short-time scale, thinning implies regular timber harvesting, further increases in wood debris cover on the ground and frequent temporary canopy cover reduction, soil and vegetation disturbance. In this sense, the advised thinning and ageing of the former coppice is likely to further modify the ground microhabitats of the former coppice, with direct consequences on the arthropod assemblages. Anyhow, the direct role of modifications of the environmental variables related to the advised silvicultural practices (i.e. thinning) has not been proved here, as we did not compare thinned and unthinned stands of similar age.

Given the specific composition of our samples, we attribute the general positive effect of increasing tree size on species richness to mature forest species. In view of this, in the former coppice of Palanfrè beech forest, the reaching of a more mature stage may lead to a progressive increase of spider abundance and carabid abundance, diversity, species richness and biomass. The specific composition of the centipede assemblages suggests a negative trend of the stand maturity towards the biomass of epigeic species, which may suffer of lower availability of trophic resources in microsites with older trees. When considering our sampling method, which underestimate edaphic species, such trend seems furthermore confirmed. The use of funnel extractor or litter sieving for example would have possibly revealed an opposite trend, as observed by Scheu et al (2003).

When considering dominant species identity, the advised management practices are expected to benefit the spider species *Coelotes osellai*, *Tenuiphantes tenebricola* and the carabid species *Pterostichus bicolor* associated with microsites with bigger trees (more mature stands). Moreover a more mature stage of the forest is expected to support bigger species of ground beetles (> 15 mm, according to Cole et al 2002), which are known to be the most threatened by anthropogenic activities (Kotze & O'Hara 2003). Among these, *Carabus solieri*, a stenoeccious species found on undisturbed chestnut and beech woods with restricted distribution in Italy and *Pterostichus bicolor* an Italian endemic.

In view of our results, the recent guidelines proposed by the Regional Administrations for the management of the beech forest of Palanfrè (Regione Autonoma Valle d'Aosta and Regione Piemonte 2006), seem in accordance with an effective conservation of the forest arthropod assemblages, at least on a long-term perspective. Interventions aimed at the completion of the conversion of the aged coppice through ageing, go along with a progressive amelioration of the forest arthropod community. With respect to the maintenance of a large degree of arthropod diversity, stand thinning may not be the most effective management, and reaching a more mature stage might be of interest. Consequently, it is important to advice that management planning should avoid maintaining traditional coppice stand (i.e. regular clear-cutting every 15 years, which would produce young phases). Such effects, associated with the removal of trees and the clear-cut

harvesting have not been directly investigated here but due to the colonization of open habitat species we may expect an increase of diversity, mainly due to the appearance of open-habitat species (Buddle et al 2000, Pearce & Venier 2006). In this case, species richness as such may not represent a valid criterion for successful conservation or forest management, but the focus should be on species that suffer from forestry operations as these are currently under severe threat. Moreover, for a better understanding of the forest ecosystem dynamics in relation to its conservation, we recommend a multitaxa approach that takes into consideration multiple aspects of biodiversity (i.e. diversity, abundance and biomass of different groups of arthropods).

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Tables

Table 1. GLMM results after model selection (backward elimination). Only significant effects in the best fitting models are shown (N: abundance; BMS: biomass; S: species richness; H: diversity; LITT: mean depth of the litter; WOOD: wood debris cover; LUM: light conditions at ground level; TREE_SIZE: mean tree size; ROCK rock cover).

Parameter	Covariate	Estimate	Std. Error	z-value	p
N (spiders)	TREE_SIZE	0.003	0.001	2.06	<0.05
BMS (centipedes)	TREE_SIZE	-9.508	4.377	-2.17	<0.05
	LUM	-11.709	2.896	-3.83	<0.01
S (ground beetles)	TREE_SIZE	7.768	4.100	1.89	<0.05
H (ground beetles)	TREE_SIZE	5.936	2.715	2.19	<0.05
N (ground beetles)	TREE_SIZE	26.905	7.640	3.52	<0.01
BMS (ground beetles)	WOOD	-124.75	48.55	-2.57	<0.05

Table 2. CCA axis summary statistics.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.098	0.039	0.022
Variance in species data			
Cumulative % explained	5.6	7.8	9.1
Pearson Correlation, Spp-Envt	0.541	0.516	0.269
Intrasect correlations for environmental variable			
1. Wood debris cover (WOOD)	-0.037	0.584	0.417
2. Rock cover (ROCK)	0.398	0.454	0.127
3. Leaf cover (LEAVES)	-0.656	-0.105	-0.317
4. Depth of the litter (LITT)	-0.562	0.358	0.132
5. Density of the trees (N_TREES)	0.339	0.638	0.171
6. Mean tree size (TREE_SIZE)	-0.637	-0.503	0.367
7. Ground light conditions (LUM)	0.029	-0.059	-0.478

Figure captions

Figure 1. Map of the study area. Black triangles indicate the position of the traps.

Figure 2. Ordination of sites in environmental space as defined by CCA, using WA scores (derived from species matrix). Triangles are sites (white= former coppice; grey= reference stand), + symbols are species.

Appendix 1. List of the spider species (adults) collected and abundance. Taxonomic order and nomenclature according to Platnick (2014).

Taxa	N° of individuals
DYSDERIDAE	
<i>Harpactocrates drassoides</i> (Simon 1882)	110
PIMOIDAE	
<i>Pimoa rupicola</i> (Simon 1884)	3
LINYPHIIDAE	
<i>Centromerus sellarius</i> (Simon 1884)	2
<i>Centromerus serratus</i> (O. P.-Cambridge 1875)	2
<i>Centromerus silvicola</i> (Kulczyński 1887)	2
<i>Centromerus sylvaticus</i> (Blackwall 1841)	1
<i>Diplocephalus picinus</i> (Blackwall 1841)	3
<i>Linyphia triangularis</i> (Clerck 1757)	1
<i>Microneta viaria</i> (Blackwall 1841)	8
<i>Neriene emphana</i> (Walckenaer 1841)	6
<i>Palliduphantes pallidus</i> (O. P.-Cambridge 1871)	5
<i>Tenuiphantes tenebricola</i> (Wider 1834)	88
<i>Turinyphia clairi</i> (Simon 1884)	1
LYCOSIDAE	
<i>Pardosa</i> gr. <i>lugubris</i> (Walckenaer 1802)	4
AGELENIDAE	
<i>Aterigena ligurica</i> (Simon 1916)	15
<i>Eratigena fuesslini</i> (Pavesi 1873)	2
<i>Coelotes osellai</i> De Blauwe 1973	246
<i>Histopona leonardo</i> Bolzern, Isaia & Pantini 2013	300
<i>Tegenaria silvestris</i> (L. Koch 1872)	2
CYBAEIDAE	
<i>Cybaeus inermidius</i> Maurer 1992	18
<i>Cybaeus vignai</i> Brignoli 1978	5
AMAUROBIIDAE	
<i>Amaurobius fenestralis</i> (Stroem 1768)	3
<i>Amaurobius ferox</i> (Walckenaer 1830)	1
<i>Amaurobius jugorum</i> L. Koch 1868	1
<i>Amaurobius scopoli</i> Thorell 1871	7
GNAPHOSIDAE	
<i>Drassodex validior</i> (Simon 1914)	1
<i>Zelotes gallicus</i> Simon 1914	1
<i>Zelotes subterraneus</i> (C. L. Koch 1833)	1
SALTICIDAE	
<i>Saitis barbipes</i> (Simon 1868)	1

Appendix 2. List of the centipede species (adults) collected and abundance.
Taxonomic order, nomenclature follows Minelli et al (2006).

Taxa	N° of individuals
Lithobiomorpha	
LITHOBIIDAE	
<i>Eupolybothrus longicornis</i> (Risso 1826)	73
<i>Lithobius dentatus</i> C.L. Koch 1844	46
<i>Lithobius lapidicola</i> Meinert 1872	18
<i>Lithobius lucifugus</i> C.L. Koch 1862	16
<i>Lithobius macilentus</i> L. Koch 1862	15
<i>Lithobius pedemontanus</i> Matic & Darabantu 1971	4
<i>Lithobius nicoeensis</i> Brölemann 1904	36
<i>Lithobius tricuspis</i> Meinert 1872	24
Scolopendromorpha	
CRYPTOPIDAE	
<i>Cryptops parisi</i> Brölemann 1920	19
Geophilomorpha	
GEOPHILIDAE	
<i>Geophilus ribauti</i> Brölemann 1908	4
LINOTAENIDAE	
<i>Strigamia acuminata</i> (Leach 1815)	4
<i>Strigamia crassipes</i> (C.L. Koch 1835)	4

Appendix 3. List of the ground beetles species (adults) collected and abundance.
Taxonomic order, nomenclature follows Vigna Taglianti (2004).

Taxa	N° of individuals
BRACHININAE	
<i>Aptinus alpinus</i> Dejean & Boisduval 1829	863
CARABINAE	
<i>Carabus convexus</i> Fabricius 1775	6
<i>Carabus problematicus</i> Herbst 1786	20
<i>Carabus solieri</i> Dejean 1826	28
<i>Cychrus attenuatus</i> (Fabricius 1792)	87
PTEROSTICHINAE	
<i>Pterostichus bicolor</i> Aragona 1830	882
<i>Pterostichus dilatatus</i> A. Villa & G.B. Villa 1835	35
<i>Pterostichus funestes</i> Csiki 1930	238
HARPALINAE	
<i>Trichotichnus nitens</i> (Heer 1838)	3
PLATYNINAE	
<i>Sphodropsis ghiliani</i> (Schaum 1858)	12
<i>Laemostenus janthinus</i> (Duftschmid 1812)	3

Figure 1

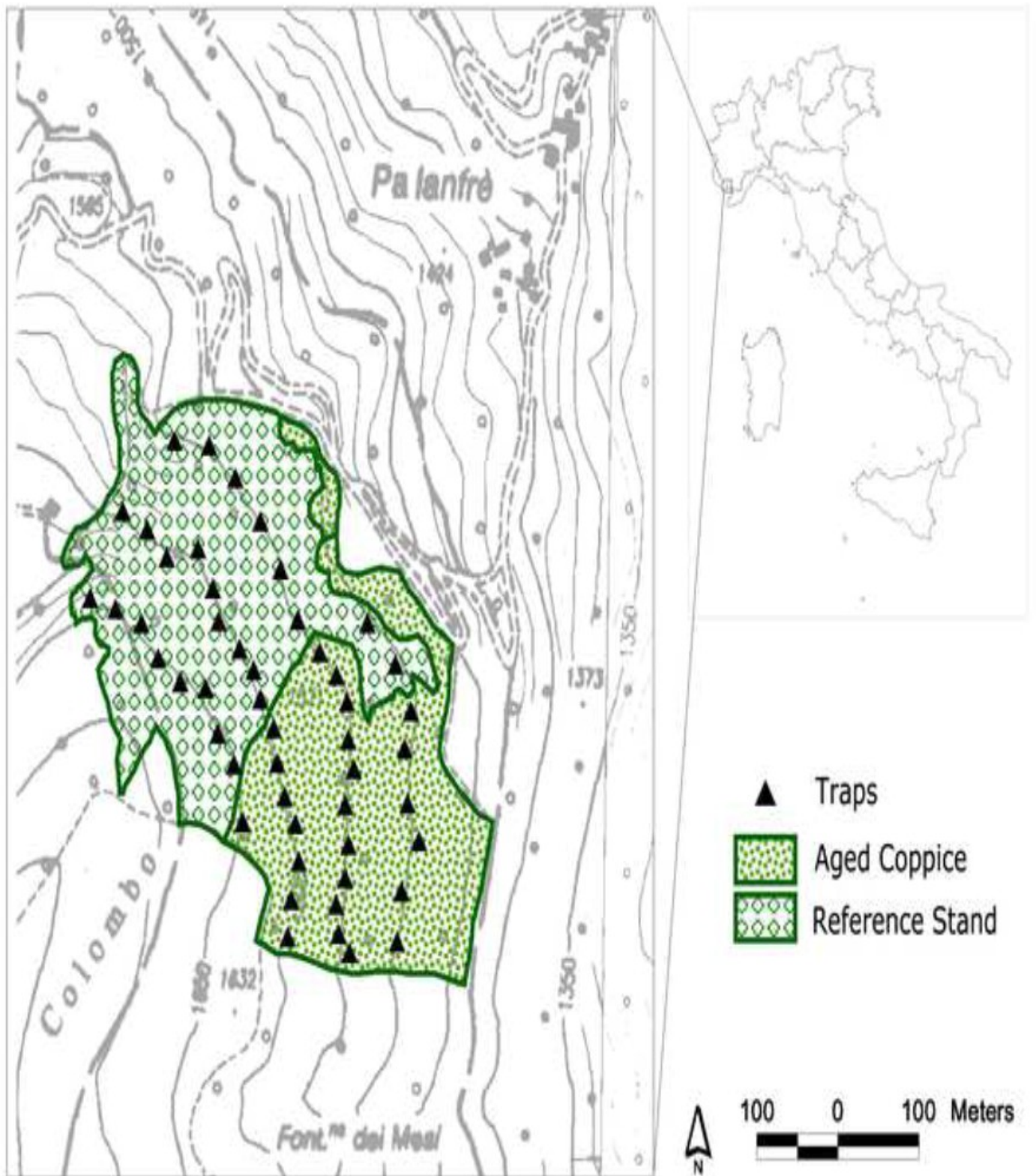


Figure 2

