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Research papers

How different management regimes of chestnut forests affect diversity and abundance of moth communities?

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Abstract - Chestnut forests have been exploited over the centuries for several uses and are still managed under coppice and orchard regimes. The different management practices have created a typical mosaic-like structure where different kinds of habitat (young and mature coppices, old thinned coppices with the physiognomy of high forest, managed or abandoned orchards) alternate in the landscape. The aim of our study was to evaluate how the different kind of management could affect the hosted biodiversity. We used nocturnal Lepidoptera as indicators, sampled in different woodlots along an altitudinal gradient in the chestnut forests of the Catena Costiera Mountains, southern Italy. We analyzed a published dataset concerning 15 stands under different management regimes. We found that the main variables affecting moth communities distribution were (i) the elevation at which the stands were located and (ii) the time elapsed from the last human intervention. In fact, the stands subjected to recent intervention (young coppices and managed orchards) showed low values of moth richness and abundance, on the contrary the stands which had not been managed recently (mature and old coppices and abandoned orchards) registered a high number of species and individuals, mainly due to their greater structural complexity. Despite the quantitative differences, in recently managed woodlots, exclusive species that increased the diversity at a landscape level were collected. Our results underlined the importance of maintaining a mosaic-like landscape taking into account also the altitude when interventions are planned in order to improve the ecological sustainability of chestnut forest exploitation.

Keywords - sustainable management; moth communities; biodiversity; *Castanea sativa*; Italy

Introduction

It is nowadays accepted that forest management should be carried out in a sustainable way, which means, at the landscape level, that the forest structure, species composition and biological diversity should remain constant over the spatial scale (Lindenmayer et al. 2000). The conservation of biological diversity, from genetic to ecosystem level, is one of the goals of ecologically sustainable forestry. One possible way to evaluate the sustainability of forest management is using bioindicators, which can reflect changes in ecosystem pattern or processes and could be represented by single species, populations, community structures or guilds (Lindenmayer et al. 2000). Lepidoptera are known to be good indicators in forest ecosystems because of their high abundance and diversity, their different ecological roles as selective herbivores, pollinators, and prey (Summerville et al. 2004). Moreover, population dynamics and community structure of forest Lepidoptera are sensitive to environmental variations and communities have been observed to respond predictably to forest management practices (Summerville and Crist 2008).

One of the most managed forest species in the Mediterranean Basin is the sweet chestnut *Castanea sativa* Mill., exploited by human activities over the centuries for both fruit and wood productions (Conedera et al. 2004, Gondard et al. 2006). Along the Italian surface, chestnut woodlands cover 788'408 hectares occupying an altitude belt comprised between 300 m to 1'000/1'200 m depending on latitude and climatic characteristics. It usually covers the vegetation belt of thermophilous forests dominated by different species of *Quercus* at low elevations and the mesophilous forests dominated by *Fagus sylvatica* at high elevations (Tabacchi et al. 2007a, Romagnoli et al. 2011, Battistini et al. 2013). The landscape dominated by chestnut assumes the characteristic mosaic-like configuration, showing patches with different structures derived by different silvicultural treatments. At present, the largest part of chestnut forests extending on the Italian surface is under two main management regimes: i) cultivated orchards (111'832 hectares); ii) coppices (593'242 ha), specialized in timber production, this last being the prevalent treatment for chestnut forests (Tabacchi et al, 2007b, Giannini et al. 2014). Coppice management will probably involve larger surfaces in the next decades because renewable energy demand is increasing (Fabbio 2016), recovering to active management the abandoned forests nowadays undergoing to natural conversion in mixed stands.

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The landscape variety obtained by different management regimes for chestnut provides a great variety of habitats occupied by several taxa with different ecological needs (Pizzolotto et al. 1991), influencing also Lepidoptera communities composition (Broome et al. 2011, Greco et al. 2016). Nevertheless, the biodiversity hosted by chestnut forests has been scarcely investigated. The importance of old trees as a resource for the species belonging to the genus *Osmoderma* (Coleoptera, Cetoniidae), such the umbrella species *Osmoderma eremita*, included in the Annexes of the Habitat Directive 92/43/EEC, is well known. Few data concerning butterfly diversity are reported in Scalercio et al. (2007). Other information about the insects related to chestnut forests specifically regard pest control, such as *Curculio* spp. (Coleoptera: Curculionidae) (Paparatti and Speranza 2005) and *Dryocosmus kuriphilus* (Hymenoptera: Cynipidae) (Quacchia et al. 2008). Recent papers concerning nocturnal Lepidoptera underlined the high diversity living in this forest type and the presence of species with conservation and biogeographic importance (Infusino et al. 2016, Greco et al. 2016). However, comprehensive checklists with phenological and abundance data in Mediterranean chestnut forests are very scarce (Infusino et al. 2018). These kind of data are of crucial importance for studying ecological changes in ecosystems and to adjust management strategies in order to improve the habitat quality in response to bioindicator needs.

In order to evaluate the effects of management regimes on diversity of moths hosted by chestnut forests, we analyzed the dataset extracted from Infusino et al. (2018) concerning the Catena Costiera Mountains of the southernmost region of peninsular Italy. The chestnut forests distributed in this mountain chain alternate woodlots subjected to recent human intervention, such as rotation cutting in coppices and ground cleaning in managed orchards, and systems with no recent management intervention, such as mature coppices, past thinnings in old coppices and abandoned orchards. We used presence/absence and quantitative data of moths and the structure of their communities as indicators of changes along successional and altitudinal gradients.

Materials and methods

Study area

In Calabria (South Italy), chestnut forests occupy 101'600 hectares, of which 69'370 ha are under cultural practices as orchards and coppices, representing one of the main forest economic resource for this region (Ciancio et al. 2004, Tabacchi et al. 2007a,b, Battistini et al. 2013). We investigated the chestnut woods of the Catena Costiera Mountains, a mountain chain extending for about 70 km along the northern Tyrrhenian coast of Calabria, between the mountains of Orsomarso in the North and the mouth of the Savuto River in the South. The geological substratum is mainly of metamorphic origin and most of the peaks do not exceed 1'400 m, with the exception of Monte Cocuzzo (1'541 m). Chestnut extended for 12'983 hectares, along the altitudinal belt comprised between 500 and 1'000 m a.s.l., delimited above by beech forests and below by oak forests, olive groves and cultivated fields. Chestnut orchards are located mainly close to residential areas, while coppices are mainly distributed far from towns and at higher altitudes. The position of the mountain chain, combined with the system of winds load of humidity that blow mainly from the west, create a microclimate characterized by persistent fog during most part of the year, mainly on the ridge and on the western slopes. Rainfall are abundant (about 1'500 mm per year), summers have mean precipitations of 127 mm and the most rainy months are from October to March/April. Average annual temperatures are different from upper and lower borders, 11.2 and 14.7°C respectively. Minimum temperature of the coldest month ranges from -7.7 to -12.3°C, maximum temperature ranges from 37.0 to 40.2°C during the hottest month (Arcidiaco et al. 2004).

Sampling method

The study was carried out using a dataset collected in two sampling years by using UV-Led light traps (further details in Infusino et al. 2018). It included 15 sampling stands, grouped in triplets located at different altitude, each triplet composed by: (1) one orchard with old trees (more than 80 years) or past thinned old coppice (≈30years); (2) one mature coppice (10-25 years); (3) one young coppice (less than 3 years). The investigated stands were also identified according to the time elapsed from last human interventions. We considered the managed orchards and the young coppices as subjected to recent intervention (occurred less than 3 years before this study), and the abandoned orchards, old and mature coppices as subjected to old interventions (occurred more than 10 years before this study) (Tab. 1).

Nine stands were investigated during the first year from May to November 2015 (CC_A_{1-2-3}; CC_B_{1-2-3}; CC_C_{1-2-3}). The second year, from April to November 2016, six new stands were investigated (CC_D_{1-2-3} e CC_E_{1-2-3}) and the triplet CC_C was

Tab. 1. - Sampling stands grouped in triplets. Geographical coordinates, provided as WGS 84/UTM 33N, elevation and description of management regime are reported for each stand.

Triplet	Stand	UTM Est (WGS 84/33N)	UTM North (WGS 84/33N)	Elevation (m a.s.l.)	Description
CC_A	CC_A1	597305.26	4354806.35	723	Abandoned orchard
	CC_A2	597338.10	4354031.43	749	Mature coppice (20-25 years)
	CC_A3	597286.88	4353884.90	734	Young coppice (less than 3 years)
CC_B	CC_B1	597450.20	4357511.91	618	Managed orchard
	CC_B2	597428.66	4357562.12	626	Coppice (15-20 years)
	CC_B3	597407.18	4358601.68	583	Young coppice (less than 3 years)
CC_C	CC_C1	596907.77	4362569.92	550	Managed orchard
	CC_C2	596647.81	4362750.45	565	Mature coppice (20-25 years)
	CC_C3	596863.17	4362822.96	545	Young coppice (less than 3 years) with standards
CC_D	CC_D1	594838.75	4361419.64	893	Old coppice in conversion to high forest (≈30years)
	CC_D2	594931.44	4361072.88	880	Coppice (10-15 years)
	CC_D3	595112.64	4361555.66	845	Young coppice (less than 3 years)
CC_E	CC_E1	595031.65	4365555.95	731	Abandoned orchard
	CC_E2	594957.41	4366778.92	815	Mature coppice (20-25 years)
	CC_E3	595068.16	4366268.10	804	Young coppice (less than 3 years)

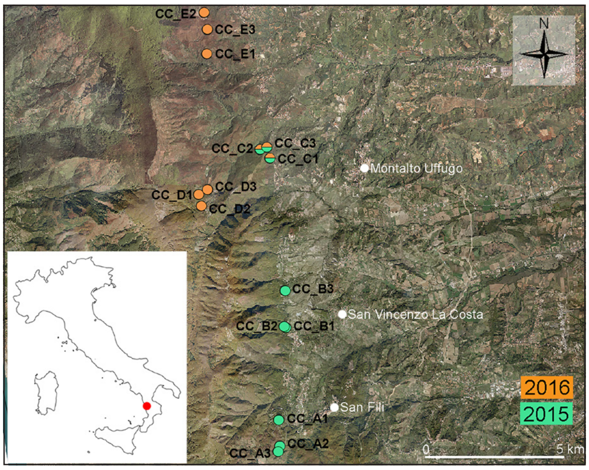

Figure 1 - Distribution of the stands sampled in two years in chestnut forests of Catena Costiera Mountains (Southern Italy). Green points indicate stands sampled during the first year (2015); orange point indicate stands sampled during the second year (2016). The stands CC_C1, CC_C2 and CC_C3 were sampled both years.

replicated resulting in two year-samples, hereafter defined as CC_Ca (2015) and CC_Cb (2016). In two sampling years a total of 15 stands were investigated (Fig. 1).

Traps were activated one night per month, during nights favorable to moth activity (i.e. low wind intensity, no full moon interference, no rainfall or just a little drizzle, not too low temperatures). Collected specimens were identified according to the available literature and stored in the collection of the Council for Agricultural Research and Economics, Research Centre for Forestry and Wood (CREA-FL), Rende (Cosenza), Italy.

Data Analyses

The whole sample collected by Infusino et al. (2018) was composed by 17'747 individuals belonging to 419 species. Comparative analyses were carried out using only data collected from May to November of both years, resulting in a stand/species matrix composed by 16'808 individuals belonging to 397 species.

A stand/species matrix was built using abundance data selecting those collected from May to November of both sampling years. In addition, we analyzed some selected natural history traits of species in order to define functional aspects of communities. Among other, we selected:

(i) host plant spectrum, defined as the amplitude of the alimentary choice of immature stages. It included monophagous species (MON), feeding on one plant genus, oligophagous species (OLI), feeding on plants belonging to the same family or on few plants of not related families, and polyphagous species (POL) feeding on a wide range of plants;

(ii) diet, defined as the vegetal matter eaten by larvae. It included species feeding on vegetal debris, fungi, lichens and mosses (FLM+DET), on herbaceous plants (HERB), on woody plants and shrubs (WP). Species feeding on more than one of the previous categories were defined as generalist (GEN);

(iii) habitat, defined as the main kind of environment exploited by species. We individuated open herbaceous formations (OHF), sub-nemoral (SN), nemoral (NEM) and bare soil (BS) as the main habitat types. Species with a large range of exploited habitats were defined as ubiquitous (UBI).

Stand/species matrix was used to compare moth communities by performing multivariate analyses. We carried out a Cluster Analysis using a paired group as the linkage algorithm and presence/absence-based (Dice) and abundance-based (Bray-Curtis) indices as similarity measures. Performing a Detrended Correspondence Analysis (DCA), we were able to group stands according to their ecological affinities. For these groups, we identified representative species as those having more than 50% of their individuals collected in a given group, present in all the stands composing a given group and rare or absent in the other groups.

Species richness (*S*), abundance (*N*) and diversity indices (Shannon, *H'*, Eveness, *E'*, Fisher's alpha) were calculated for each group of stands obtained by DCA. In order to estimate the total species richness (S_{Chao1}) of a given sample, we used the Chao1 index, a non-parametric algorithm based on the number of singletons and doubletons (Cazzolla Gatti 2014). Species richness and abundance of DCA groups were compared using a median test because data were not normally distributed.

Statistical analyses were performed using the free software Past, version 3.08 (Hammer et al. 2001).

Results

The most common species were composed by *Peribatodes rhomboidaria* (Geometridae), *Clemathada calberlai* (Noctuidae) and *Paracolax tristalis* (Erebidae), which correspond to the 23.11% of the total abundance (Fig. 2).

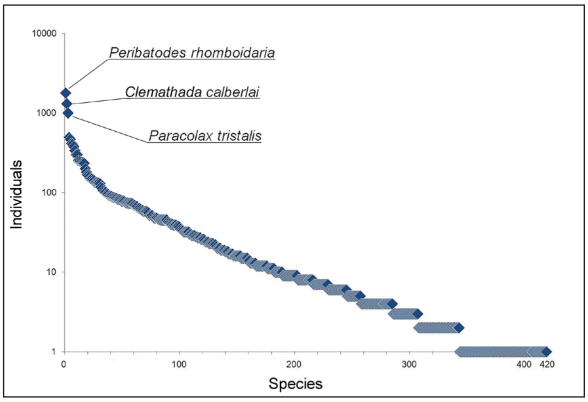

Figure 2 - Abundance distribution of the whole moth community sampled in chestnut forests in two years. The name of the three most abundant species are reported at the head of community.

The first is a quite common polyphagous species, feeding on woody plants and shrubs. The remaining two are both oligophagous and subnemoral, *C. calberlai* feeds on herbaceous plants and *P. tristalis* feeds on vegetal debris. 77 singletons (18.3% of species) composed the long tail of the whole community.

Species traits were more or less equally represented in term of species richness and abundance, especially the host plant spectrum, while diet and habitat showed only few, and expected, differences (Fig. 3). Concerning the host plant spectrum, polyphagous species were the most rich and abundant, followed by oligophagous and monophagous species. The largest portion of the community is characterized by larvae feeding on herbaceous plants, but their abundance was lower than their richness. Woody plant feeders and generalists were also well

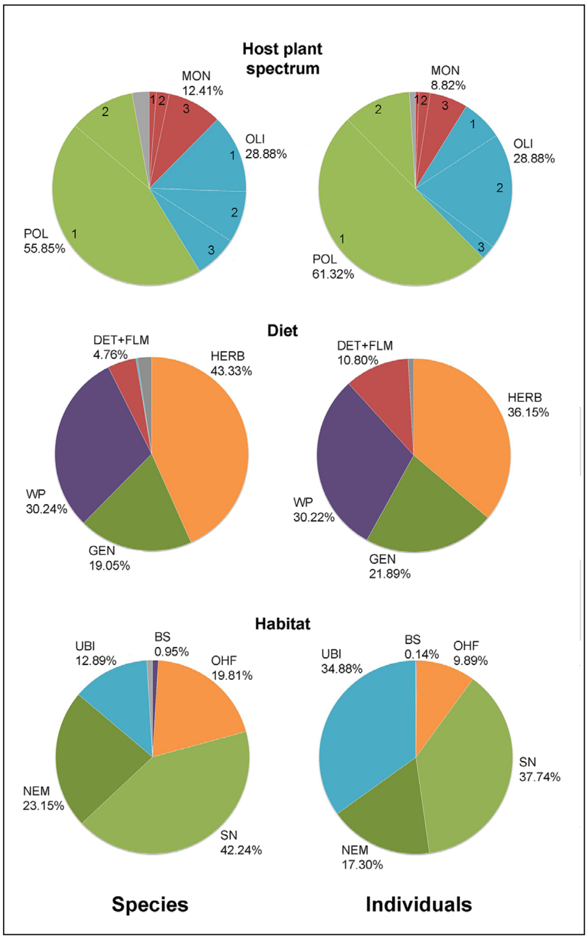

Figure 3 - Ecological traits and percentages of species (S) and individuals (N) representing each category. Host Plant Spectrum: monophagous (MON) partitioned in species/individuals feeding on (1) one single host plant, (2) some plants of the same genus, (3) all plants of the same genus; oligophagous (OLI), partitioned in species/individuals feeding on (1) few plants of the same family, (2) few representatives of related families, (3) single representatives of not related families; polyphagous (POL) partitioned in species/individuals feeding on (1) numerous plants belongings the same class, (2) a very wide host plant spectrum. Diet: species/individuals feeding on herbaceous plants (HERB); species/individuals feeding on woody plants and shrubs (WP); species/individuals feeding on fungi, lichen, mosses and vegetal debris (FLM+DET), species/individuals feeding on more than one of the previous categories, having thus a generalist diet (GEN). Habitat: species/individuals preferring open herbaceous formations (OHF); species/individuals living in subnemoral (SN) and nemoral (NEM) areas; species/individuals ubiquitous (UBI); species/individuals preferring bare soils (BS). Species/individuals whose ecological traits are unknown are in grey.

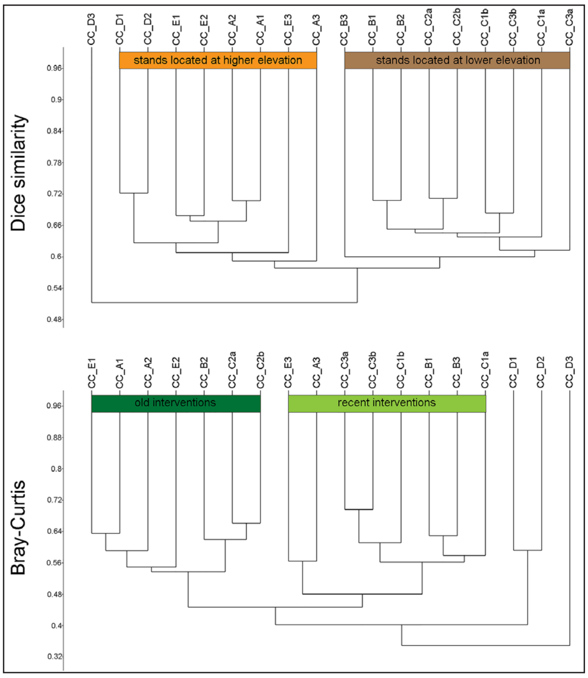

Figure 4 - Cluster Analysis performed using Dice similarity algorithm (upper) grouped the stands according to the altitude. Cluster analysis performed using Bray-Curtis (below) grouped the stands according to the time elapsed from the last human interventions.

represented, but stable as species and individuals. Larvae feeding on detritus, fungi, lichens and mosses were twice more abundant than rich, being the only diet guild showing appreciable changes. Only one species with carnivorous habits was collected, the Erebidae *Eublemma scitula*, predator of Homoptera Coccidae. Concerning habitat preferences, the greatest portion of species was nemoral and subnemoral. Their abundance had only a slightly lower incidence and species preferring open herbaceous formations were halved. On the other hand, ubiquitous individuals tripled their percentage (Fig.3).

Cluster Analysis showed different results depending on the utilized similarity measures. The use of the presence/absence-based index (Dice) grouped the stands according to their altitude, clustering together the triplets located up to 700 m a.s.l. (CC_A, CC_D and CC_E) with exception for the stand CC_D3, and those located at lower elevation (CC_B, CC_Ca,b). The use of the abundance-based index (Bray-Curtis) produced different groups, clustering together mature coppices (CC_A2, CC_B2, CC_C2a,b and CC_E2) with abandoned orchards (CC_A1 and CC_E1) which were subjected to old interventions, and young coppices (CC_A3, CC_B3, CC_C3a,b, CC_E3) with managed orchards (CC_B1 and CC_C1a,b) which were subjected to recent interventions. The stands CC_D1, and CC_D2 clustered in an isolated group and CC_D3 did not belong to any cluster (Fig. 4).

In the Detrended Correspondence Analysis the first two Axis explicated the 35.73% of the whole variance. The multivariate assessment distributed the stands according to elevation along the Axis 1 (Pearson r=0.84; p<0.001) and according to the time elapsed from the last human intervention along the Axis 2 (Pearson r=-0.63; p<0.01), both variables recognized also by Cluster Analysis. Consequently, we were able to highlight four main groups in the Cartesian plan: the first represented by stands located at lower elevation subjected to recent interventions, the second included the stands located at lower elevation subjected to old interventions, the third represented by the stands located at higher elevation subjected to recent interventions, and the fourth composed by the stands located at higher elevation subjected to old interventions. It is interesting to underline that communities sampled in the replicated stands (CC_C1a,b, CC_C2a,b and CC_C3a,b) were grouped consistently among years. The autoecology of the representative species supported the ecological interpretation of DCA axis (Fig. 5).

Tab. 2.- Observed species richness (Sobs), number of individuals (N), total estimated specie richness (SChao1) and percentage of the really sampled total estimated richness (%), Shannon (H’), Eveness (E’) and Fisher’s alpha diversity indices were reported for each group identified by multivariate analyses.

DCA Groups	S_{obs}	N	S_{Chao1}	%	H’	E’	Fisher’s alpha
LR	269	4043	359	74.93	4.27	0.27	64.84
LO	282	5157	329	85.64	4.42	0.29	64.09
HR	208	1521	277	75.08	4.21	0.32	65.16
HO	292	6087	342	85.41	4.36	0.27	63.95
LR U HR	316	5564	421	75.06	4.37	0.25	72.61
LO U HO	358	11244	415	86.33	4.48	0.25	70.50

Legend. LR: stands located at lower elevations subjected to recent interventions; LO: stands located at lower elevations subjected to old interventions; HR: stands located at higher elevation subjected to recent interventions; HO: stands located at higher elevation subjected to old interventions. LR U HR: groups of stands subjected to recent interventions; LO U HO: group of stands subjected to old interventions.

Groups obtained by multivariate analysis, were used to coherently analyze the diversity of moth communities. In general, woodlots subjected to recent interventions showed richness and abundance values lower than those subjected to old interventions, while diversity indices are quite comparable (Tab. 2). Furthermore, we observed that the actually sampled percentage of the total estimated richness in stands subjected to recent interventions was lower than in stands subjected to old interventions, mainly because singletons were more represented in the former (7.43%) than in the latter (1.03%).

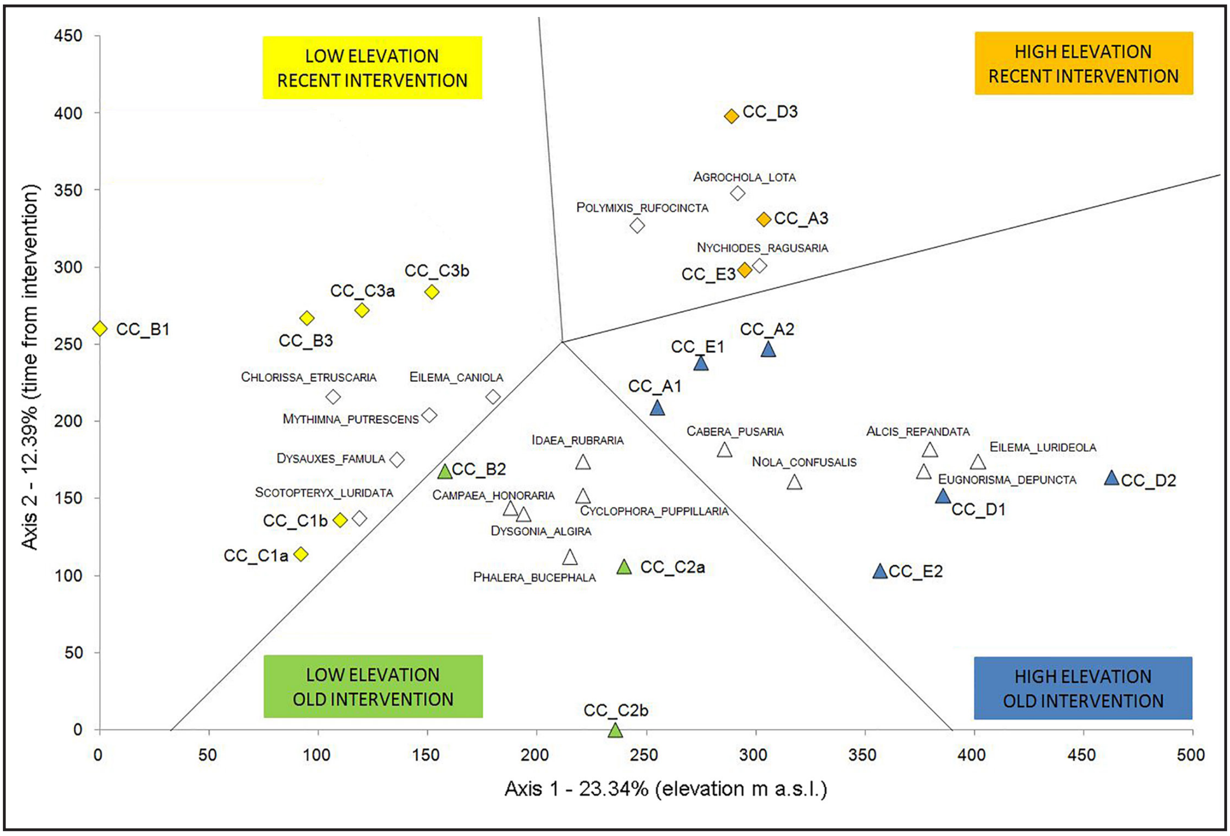

Figure 5 - DCA ordination of stands and most representative species according to the main variables: elevation (Axis 1) and time elapsed from the last human intervention (Axis 2). Diamonds indicate stands subjected to recent interventions, triangles indicate stands subjected to old interventions. Representative species are indicated with empty symbols. Four groups are identified: stands located at lower altitude subjected to recent interventions (yellow); stands located at lower altitude subjected to old interventions (green); stands located at higher altitude subjected to recent interventions (orange); stands located at higher altitudes submitted to old interventions (blue).

Richness and abundance of the stands recently managed, included in the LR and HR DCA groups (Tab. 2), were significantly lower than those of the stands subjected to old interventions. CC_C1b stand represented an outgroup among stands recently managed (Fig. 6).

Discussion

We found that the main variables influencing moth community composition were altitude and time elapsed from the last human intervention, while diversity and abundance were modified by the latter variable.

It is largely known for Lepidoptera that along an altitudinal gradient differences in species composition and community structures could be affected also by changes in host-plants availability, competitors/parasitoids/predators interferences, changes in habitat characteristics (exposure, soil nutrients, temperatures etc.) (Brehm and Fiedler 2003, Hodkinson 2005). We found that species composition was clearly affected by altitude, while diversity was quite constant along the altitudinal gradient. High-altitude woodlots inhabited species usually present at high elevations in the Calabria region, such as *Alcis repandata*, *Eilema lurideola* and *Eugnorisma depuncta*. None of these species is trophically related to forest cover being generalist, lichen- and herb-feeders, respectively. Furthermore, few abundant species were related to beech, the forest type that develops near chestnuts at high altitudes. At low altitude more thermophilous and Mediterranean species occurred, such as the lichenivorous *Eilema caniola*, and the polyphagous *Dysauxes famula* and *Idaea rubraria*. As observed at high altitude, only few abundant species were trophically linked to trees such as oaks. In general, we observed that moth communities were mainly determined by abiotic parameters, such as altitude, and by biotic parameters such as the floristic composition of the understory, having chestnut a marginal role as host plant for moth larvae.

The most interesting result of this paper was to identify the time elapsed from the last human intervention as a key factor determining richness and abundance of moth communities. Our analyses separated mature coppices and abandoned orchards from young coppices and managed orchards, underlying that these types of woodlots were inhabited by communities with different composition, i.e. composed by species having different ecological needs, and with different abundance and diversity. In fact, species richness and abundance were significantly

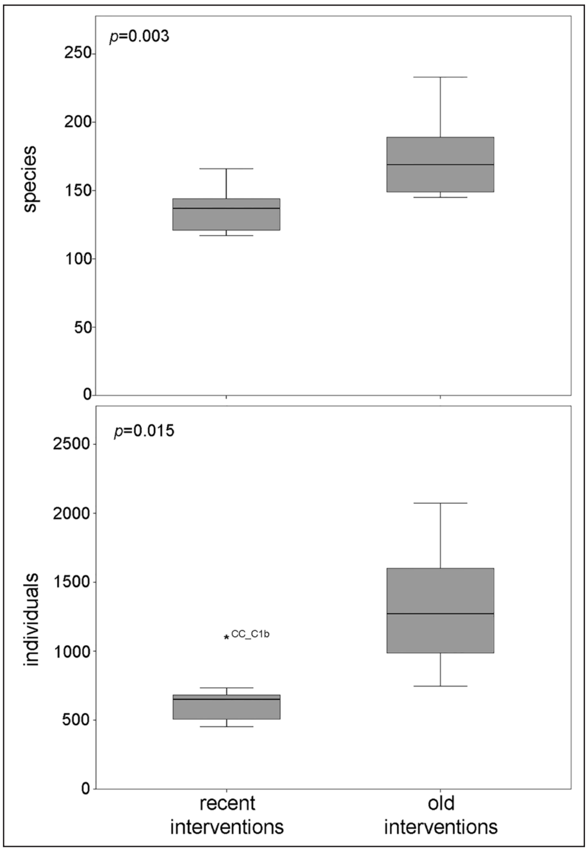

Figure 6 - Box plots of species and individuals sampled in the stands grouped according to the time elapsed from the last human interventions. The p values of the median test are also reported in the graphs.

higher in chestnut stands where human interventions had occurred at least ten years before the sampling, without differences between coppices and orchards.

From a vegetation point of view it was observed that at the end of the coppice rotation cutting activities drastically reduce the structural complexity of woodlots but, on the other hand, allow the rapid ingression of pioneer plant species, increasing the vegetal diversity over time (Gondard et al. 2001). As the chestnut sprouts grow up, the canopy becomes denser favoring the settlement of more shade tolerant species, and reaching a quite stable diversity level, as observed in abandoned orchards (Gondard et al. 2001). Similarly, moth communities become more stable in mature coppices and abandoned orchards, as showed by the higher fraction of estimated total richness sampled in these chestnut forest portions. As suggested by Summerville and Crist (2008), Lepidoptera species and community structures in managed forests differ according to the age of stands, the shrub community composition and the composition of the matrix surrounding the stands. In older stands, with larger trees and a higher shrubs diversity, the species richness is usually higher than in open habitats thanks to the availability of numerous niches. Higher values of richness and abundance in stands with older trees was observed also in our results, with the exception of managed orchards, in which ground cleaning actions prevent the development of structural complexity and affect moth communities. In older stands the number of species feeding on vegetal debris, fungi, lichen and mosses is usually higher than in open habitats (Broome et al. 2011), as we also observed in Calabrian chestnut forests. In detail, the detritivore *Paracolax tristalis* was one of the dominant species of the whole community, being largely more abundant in mature coppices and abandoned orchards than in young coppices and managed orchards. *Tephronia sepiaria*, *Cryphia algae* and *Eilema lurideola*, species feeding on fungi, lichens and mosses, had a similar distribution being at least 80% more abundant in mature coppices than in the young ones.

At woodlot scale human activities seem to be detrimental for moth diversity and abundance. Nevertheless, at a larger scale they appear to be necessary to maintain a diversified biota in a perturbation-dependent habitat such as chestnut forests (Gondard et al. 2001). As observed in previous papers (Broome et al. 2011, Bullman 2007, Greco et al. 2016), we confirmed that the creation of a variety of habitats resulting by coppicing and orchard management is important for increasing the moth diversity within woodlands, favoring the presence of species having different ecological needs. In fact, high perturbed woodlots hosted several exclusive species, contributing for about the 10% to the diversity at the landscape level.

The prescribed management of this forest type by Calabria regional policies (VV. AA. 2008) is in agreement with a sustainable forestry as demonstrated by the presence of species of conservation concern such as *Euplagia quadripunctaria* (Annex II of the Habitat Directive 92/43/EEC), and several species of biogeographic interest (Infusino et al. 2016). Moreover, the return to an active coppice management was observed to maintain high levels of vegetation diversity (Ciancio et al. 2006, Vacik et al. 2009). Keeping in mind that a sustainable forestry should also guarantee biodiversity conservation, coppice management practices should be carried out considering the faunal communities associated with plant diversity. In order to improve this sustainability we suggest to take into account also the altitude as a key factor in coppice rotation planning with the aim of providing a diversified mosaic of habitats for biodiversity along the altitudinal gradient. In this way, the altitude-balanced mosaic-like landscape created by chestnut management will pursuit the economic exploitation of chestnut forests for timber and fruit production with a high sustainability, contributing to maintaining high levels of biodiversity also in perturbed landscapes.

Acknowledgements

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