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Spatial patterns of saproxylic beetles in a relic silver fir forest (Central Italy), relationships with forest structure and biodiversity indicators

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ABSTRACT

The conservation of biological diversity is one of the main goals for managing forests in an ecologically sustainable way. Presence and abundance of microhabitats, such as tree cavities or bark pockets, can be conveniently used as indicators to evaluate the effectiveness of sustainable forest management measures. In Mediterranean forest ecosystems, the relationships between stand-structure attributes and species-diversity indicators are still poorly studied.

We described the structural attributes, deadwood characteristics and microhabitat occurrence in a silver fir forest of Central Apennines (Italy), which has not been submitted to silvicultural interventions for several decades. We assessed linkages between these characteristics and the abundance, distribution and diversity of saproxylic beetle fauna. A systematic aligned sampling method was conduced on 240 ha, examining 50 plots of 530 m^2 each. Saproxylic beetles were sampled using window flight traps and emergence traps in relation to abundance and species richness at the plot level, but also on decaying deadwood. The heterogeneity in types and frequencies of microhabitats, and the link between structural attributes associated with stand complexity and saproxylic species, were also analysed. With the aim of describing the complex saproxylic ecological network, beetle species were classified according to the type of interactions with wood and other insects fauna, but also in relation to the trophic guilds. Linear regressions were conducted for highlighting metric variability and relationships between parameters, while geostatistical analyses were used to describe the spatial variability of structural features and the spatial pattern of beetle distributions.

Results of linear regression and geostatistical analysis showed how the saproxylic beetle community is influenced by the amount, type and stage of decay of deadwood, but also by the forest structural complexity and the occurrence of microhabitats. Gap dynamics and natural disturbances had effects on deadwood amounts and microhabitat abundance, which was significantly higher than in managed and structurally simplified forest stands. Most of the entomological variables (namely, Families, Species, Total individuals, Saproxylic individuals, Staphylinidae, Elateridae, *Nothodes parvulus*, Curculionidae, *Ernoporus fagi*, *Phyllobius emery*) were clumped, highlighting the existence of aggregation areas in the sampled forest. In several cases the insect distribution was linked to the spatial pattern of forest attributes, particularly deadwood components.

1. Introduction

The relationship between forest structure and biodiversity has been widely investigated. For example, the variation in tree size, the occurrence of large living old trees and the presence of multi-layered forest canopies have been used as indicators of biodiversity (Franklin and Van Pelt, 2004). The heterogeneity in tree heights, high values of living volume and basal area have been considered, indeed, features affecting the forest naturalness (Peterken, 1996). The amount of deadwood has also been recognized as one of the main factors to be considered for conservation purposes, and large amounts of standing, dead downed trees and

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woody detritus on the forest floor in all stages of decay are important components for the maintenance of forest biodiversity (Grove, 2002; Della Rocca et al., 2014). In Mediterranean montane forests, research on this issue has been focused on describing the interaction between structural features (Lombardi et al., 2012; Motta et al., 2006), their association with species diversity (Balestrieri et al., 2015; Burrascano et al., 2008) and on the effects of forest management on stand naturalness (Regnery et al., 2013). Growing stock, woody increments and deadwood amounts are also considered as biodiversity indicators at pan-European level by the Streamlining European Biodiversity Indicators (SEBI) initiative (SEBI, 2011).

Occurrence of microhabitats and their abundance in relation to the forest structure are features to be considered for planning forest monitoring and biodiversity conservation actions. Nevertheless, it remains poorly explored in quantitative terms, if compared with other indicators related to biodiversity evaluation (Wijewardana, 2008). Indicators based on structural attributes are helpful since they can both represent a good proxy of ecosystem functions and a measured surrogate for habitats of many taxa (Franklin et al., 2002). Microhabitats, such as dead branches, stem cavities, cracked and loose bark, conks of fungi, occurring on living trees and deadwood, substitute or secondary crown, are also considered useful in monitoring (Vuidot et al., 2011; Winter and Möller, 2008) and have a significant effect on biodiversity (Bouget et al., 2013). Several studies have stated the importance of microstructural features for nesting, roosting and feeding birds (Bassler et al., 2012; Kotze et al., 2011; Remm et al., 2006), and supporting large invertebrate communities, which become a rich source of food (Laiolo et al., 2004). Very specialized species are associated with to dendrothelms, temporary rain-fed water bodies on trees (Kitching, 1971), while saproxylic fungi are the habitat for a rich diversity of insect fauna (Gouix and Brustel, 2011). Therefore, tree microhabitats support a large food chain, having an important role in the functioning of forest ecosystems (Aitken and Martin, 2007). The relationship between wood-dependent saproxylic species and forest structural indicators was investigated mainly in central and Northern Europe (Ranius and Janssonm 2000; Ranius et al., 2003), but received much less attention in the Mediterranean mountainous geographical context (Persiani et al., 2015; Sabatini et al., 2016).

The spatial relationships among forest structural attributes and biodiversity richness have a crucial role in the maintenance of the ecological connectivity between different habitat patches (Grove, 2002). The community dynamics of arthropods depend on the complexity and integrity of the habitat structure of ecosystems (Maleque et al., 2006). In this context, forest fragmentation, disturbance intensity and forest management impact on both the quantity and quality of deadwood and the heterogeneity of microhabitats, also during post-disturbance (including forestry practices) recovery (Regnery et al., 2013). The spatial pattern of forest attributes, in particular deadwood, in relationship with saproxylic insects needs further exploration to understand the effect of forest use and dynamics on detritus recycling (Bouget et al., 2013; Holland et al., 2004; Sverdrup-Thygeson et al., 2014). It is well recognized that insects are a significant component of the saproxylic food web related to deadwood (Grove, 2002) and, among insects, Coleoptera are particularly important agents, together with fungi, in the wood decomposition processes (Stokland et al., 2012).

In this study, we report the results obtained from the spatial pattern analyses of forest structural indicators and the sampled coleopteran fauna in a relic silver fir (*Abies alba* Mill.) forest stand located in the Central Apennines (Italy); the investigated forest has been subjected to very limited management practices in the last 60 years. The main purpose of the study was to investigate the spatial relationships between the coleopteran fauna components and the forest structural attributes, namely deadwood and microhabitats, evaluating which environmental factors could influence the occurrence and distribution of insects. We hypothesized that species richness and abundance of saproxylic fauna varied with the stand characteristics and deadwood occurrence (volume and type), but also that the spatial patterns of these attributes exert a significant role in determining the distribution of insects into the investigated forest stand.

2. Material and methods

2.1. Study area

The study was conducted in the *Abeti Soprani* silver fir forest, located in the Central Apennines, Italy (Fig. 1); see Lombardi et al. (2008) for details. This relict forest is an uneven aged stand, with an average age of 90–100 years; it extends over 343 ha, at an altitude ranging from 1000 to 1500 m a.s.l., with a north facing slope. The site is considered representative of the montane beech and coniferous forests of the Mediterranean, Anatolian and Macaronesian regions (EEA, 2006).

Forest structure and composition are similar to those common in the past throughout the Apennines, nowadays surviving only in small areas of the Italian Peninsula (Ciancio et al., 1985). The stand has not been cut since 1960 due to the low local interest in conifer timber and, thus, the current natural development processes are the main drivers of the stand evolution.

The forest is an almost pure *A. alba* stand, associated with *Fagus sylvatica* L. at the highest altitudes and with *Quercus cerris* L. at the lowest altitudes. In the community, other species such as *Acer campestre* L., *A. obtusatum* W. et K., *A. pseudoplatanus* L., *Taxus baccata* L., *Carpinus betulus* L., *Tilia platyphyllos* Scop., *Ulmus glabra* Hud., *Pyrus pyraster* Burgsd., *Fraxinus ornus* L., *Sorbus torminalis* Crantz., and *Malus sylvestris* Mill. occur.

2.2. Sampling scheme

The experimental area extends over 240 ha. Overall, 50 sampling plots were selected: 43 were positioned at a regular distance of 250 m to each other, using a systematic aligned scheme; 7 plots were randomly positioned at shorter distances to better represent the spatial micro-variability.

For each sampling station, UTM datum WGS 1984 coordinates (Zone 32T) and altitude (m a.s.l.) were recorded using the Juno SB Global Positioning System (GPS) (Trimble, Sunnyvale, California).

In each plot, a complete survey of living trees and deadwood attributes, the assessment of microhabitats and the sampling of saproxylic beetles were carried out as detailed in the following sections.

2.3. Living trees and deadwood survey

The sampling plots of 13 m of radius were established and clearly delimited. The main characteristics of each plot were also recorded. Living trees (minimum diameter at breast height, DBH, $\geqslant$10 cm) and deadwood (minimum diameter $\geqslant$ 5 cm) were totally measured, marked and numbered.

The information recorded on the plots comprises tree DBH and height, canopy cover, species both for living trees and deadwood. Particularly, dead downed trees, snags, coarse woody debris and stumps were included in the survey, measuring their length/height, minimum and maximum diameter and recording the species, when recognizable. Standing dead trees were characterized by the presence of crown (dead branches and twigs), while snags