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Effects of forest management on ground beetle diversity in alpine beech (*Fagus sylvatica* L.) stands

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A B S T R A C T

European beech forests are of particular importance for biodiversity, although relatively little is known about how beech forest management impacts on invertebrate communities. In this paper we investigated the influence of beech forest management history [i.e. over-mature coppices (OC) and coppices in conversion to high forests (CCHF)], climatic, topographic and microhabitat characteristics on ground beetle diversity (measured as total relative abundance, species richness, Shannon diversity and abundance of the endangered endemic species *Carabus olympiae*) in northern Italy. The diversity of forest specialist carabids was higher in OC and in forest stands characterized by a higher mean temperature and lower relative humidity. Moreover, we detected a positive response of several diversity variables to coarse wood debris cover or volume, herb cover, and the standard deviation of tree diameter. Currently, OC seems to be a more favorable habitat for forest carabids, including *C. olympiae*, although succession over time can lead to a progressive homogenization of the vegetation structure, with negative consequences for the conservation of the forest carabid assemblage.

Based on our results, we suggest that the traditional management of beech coppice and its conversion to high forest be modified by including practices aimed at promoting structural and microhabitat diversity such as retention of large trees, creation of canopy gaps, retention of coarse wood debris and the preservation of 'islands' of older trees in the managed stands.

1. Introduction

In Europe, Beech *Fagus sylvatica* forests are of particular importance for biodiversity. Annex 1 of the "Habitats Directive" (92/43/EEC) lists eight habitat types characterized by beech forests as worthy of conservation. Current threats to beech forest ecosystems include climate change (Gessler et al., 2007; Di Filippo et al., 2012), increased likelihood of drought and fire damage (Piovesan et al., 2008; Ascoli et al., 2013), impact of tourism (Negro et al., 2009; Rolando et al., 2013), habitat loss and fragmentation (Kunstler et al., 2007), grazing by domestic or wild ungulates (Vandenberghe et al., 2007; Olesen and Madsen, 2008) and changes in forest management (Mund and Schulze, 2006; Wagner et al., 2011).

There are few studies concerning the effect of forest management on biodiversity in beech forests (e.g. Moning and Müller, 2009; Spiecker, 2003), and most of these focus on plant or mycorrhizal diversity (e.g. Van Calster et al., 2007; Bartha et al., 2008; Di Marino et al., 2008; Radtke et al., 2013). However, such information is a necessary pre-requisite for management of this habitat given the various environmental pressures to which it is subject. A case in point are the beech forests which characterize the landscape of many mountain areas in Italy (Nocentini, 2009). Most beech forests are currently managed as coppice, i.e., by repeatedly cutting back shoots to ground level to stimulate vegetative growth and provide firewood on a short rotation basis (20–40 years). High forests where trees are regenerated by seed are rare. However, many coppices are now transitioning to a high-forest structure, due to either the abandonment of regular management, or silvicultural conversion by thinning (Nocentini, 2009), yet the impacts of such management changes on biodiversity are not as yet fully understood.

Insects respond to stand structural complexity at different temporal and spatial scales, and they are strongly influenced by natural and anthropogenic disturbance (Kraus and Krumm, 2013). In particular, ground beetles (Coleoptera: Carabidae) cover a wide range of life histories and microhabitat requirements, and therefore they

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have been widely recommended as bioindicators of forest management (Rainio and Niemelä, 2003). They are relatively easy and cost-efficient to assess with standardized methods (i.e., pitfall trapping), and are sensitive to environmental factors such as temperature, humidity and vegetation structure (Stork, 1990; Butterfield, 1996; Lövei and Sunderland, 1996). Furthermore, changes in carabid abundance and species richness can be useful tools to evaluate the effects of human disturbance in forest ecosystems (Brandmayr et al., 2009).

Most of the studies of carabid diversity in forest habitats have focused on the effects of habitat fragmentation (Davies and Margules, 1998; Niemelä, 2001; Koivula and Vermeulen, 2005), edge effects (Heliölä et al., 2001; Koivula et al., 2004; Negro et al., 2009), or forestry practices (Werner and Raffa, 2000; Pearce and Venier, 2006; Taboada et al., 2006). The latter affect particularly large-sized and brachypterous (short or reduced wings) habitat specialists, which have limited dispersal capacity (Kotze and O'Hara, 2003). Indeed, several authors have demonstrated that flight capability, and therefore dispersal ability, is a function of carabid wing form (Den Boer, 1970, 1990; Lövei and Sunderland, 1996). For example, radio-telemetry in the same beech forest stands considered in this study has shown that the endangered *Carabus olympiae* has very low dispersal (Negro et al., 2008).

We focused on a group of localized, medium and large-bodied brachypterous ground beetles inhabiting beech forests in the north western Italian Alps. The study site, located in the Sessera Valley, is part of Natura 2000 ecological network. In particular, the site houses *C. olympiae,* classified as a priority species in Annexes II and IV of the "Habitats Directive" (92/43/EEC) and considered Vulnerable according to the IUCN red list of Threatened species (http://www.iucnredlist.org/).

In this study, we considered the response of forest carabid beetles to management history (i.e. coppice or coppice in conversion to high forest), habitat structure and micro-climate in beech forests in northern Italy, in order to understand the factors affecting their abundance and diversity, and hence to better inform management strategies for their conservation. The specific aims were: (1) to test whether two different management histories [i.e., over-mature coppice (OC) and coppice in conversion to high forests (CCHF)], in the same beech forest ecosystem, have different effects on the abundance, species richness, diversity and composition of forest carabid assemblages; (2) to assess which vegetation and stand structure parameters are more important in driving forest carabid abundance and diversity, and (3) to evaluate which are the best forest management practices, if any, for long-term conservation of the endemic species *C. olympiae*.

2. Methods

2.1. Study area

The study area was the Upper Sessera Valley (Fig. 1), about 108 km^2 wide, located in north-east Piedmont, Italy (45°40′N, 8°16′E). It includes the upper part of the River Sessera basin, a mountainous catchment, from the valley bottom up to an elevation of 2556 m a.s.l. (average elevation: 1350 m). Annual rainfall is 1700 mm with two equinoctial maxima, and mean annual temperature is 7 °C. Snow cover lasts about 5 months (November to March).

Due to its position at the outer margins of the Alps, the Upper Sessera Valley provided a glacial refugium for many plant and animal genera, and is now a local hotspot for biodiversity. The most common land cover classes are pasture (dominated by graminaceous plants), shrubland (alpen rose *Rhododendron ferrugineum* L. and blueberry *Vaccinium myrtillus* L.), secondary forest on former pastures (birch *Betula pendula* L. and common hazel *Corylus avellana* L.), and beech (*F. sylvatica* L.) forest (belonging to the association *Luzulo-Fagetum*). Moreover, large portions of the site were afforested by conifer plantations (Norway spruce *Picea abies* (L.) Karst) and other conifers before and after World War II.

In the study area, beech was traditionally coppiced to produce firewood and charcoal. Over the last decades, forest management has been progressively abandoned. The last harvest in privately owned coppice stands was carried out in 1960. The sprouts are 53 years old and most of the standards are about 80 years old. On the other hand, most coppices on public properties have been actively converted to high forest since the 1980s. The traditional treatment applied to coppice was the coppice with standard (an average of 100 standards per hectare) and the conversion has been applied with a gradual thinning of sprouts (Giannini and Piussi, 1976). This method requires a first thinning in an over-mature coppice, and 2–3 further thinnings before reaching the final step defined as "temporary high forest" (a forest that has the structure of a monolayered high forest, but that, at the same time, originated from sprouting). The application of a seeding cut (i.e. to provide growing space for the regeneration to establish and shelter for the young developing seedlings) on the temporary high forest represents the end of the conversion process, producing an even-aged high forest stand. Most of the CCHF plots are currently between the second and the third thinning and the trees are 70–75 years old, with some standards > 100 years old.

2.2. Sampling design

Monitoring and conservation actions were carried out in a study area of 54 ha, including beech forest, afforestation, and shrubland. Among beech forests, 24% were publicly owned (CCHF) and 76% were private (OC that have passed the traditional rotation period). Therefore, a stratified sampling design was used to select plots managed as OC and CCHF. A total of 31 plots, established at the nodes of a 100 × 100 m grid overlayed by beech forest cover, were selected. The number of plots was set in relation to the area occupied by each management system, i.e., 10 in CCHF and 21 in OC stands (Fig. 1).

We used baited pitfall traps to sample the carabid community in the study area. Catches with pitfall traps can be used to estimate the density of carabid beetles (Baars, 1979), but as stressed by several authors (e.g. Niemelä et al., 1993a,b; Kinnunen et al., 2001), they are better adapted for comparing species richness, abundance and Shannon diversity between different habitats (Andorko and Kadar, 2006; Mathe, 2006) or, as in our case, between different forest management systems (du Bus de Warnaffe and Lebrun, 2004).

In each sampling plot, five pitfall traps were arranged according to a Latin square design, i.e., at the four vertices and at the center of a 20 m-wide square. Pitfall traps were placed at the end of May 2013 and emptied on average every 4 days (ranging from three to six) until the end of August (equal to 18 sampling periods). Each trap (7.5 cm diameter and 9 cm deep) was assembled with a double bottom in order to keep animals alive, and filled with 150 ml of vinegar as an attractant (van den Berghe, 1992). A flat stone was positioned 3 cm above each trap to prevent flooding. Identification of the carabids was carried out in the field following the nomenclature of Audisio and Vigna Taglianti (2004).

Thermo/Hygro Button 23 loggers (Maxim Integrated Products, Inc., Sunnyvale, CA, U.S.A.) were used to record temperature and relative humidity in each sampling point. The buttons were fixed to wooden poles (2 cm above the soil surface) and were sheltered from rain by means of a plastic roof. The data loggers measured the temperature and the relative humidity every 1 h and were run for the entire sampling period (about 3 months). In the lab, we