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Effects of forest heterogeneity on the efficiency of caterpillar control service provided by birds in temperate oak forests

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ABSTRACT

Controlling herbivore insects by insectivorous birds is a major ecosystem service, nevertheless little is known about how local habitat features and forest management influence the efficiency of this service and about how the pest control service birds provide can be maintained and improved. We conducted an experiment in temperate oak forests in the Mátra Mountains, northern Hungary to measure bird predation rate of artificial caterpillars resembling winter moth (*Operophtera brumata* L.) larvae, to evaluate the relationships among insectivorous bird communities, caterpillar populations and leaf damage caused by caterpillars and to assess the effect of forest heterogeneity on these processes. We found, that structurally heterogeneous forests maintained a significantly higher abundance of insectivorous birds. Especially the tree size heterogeneity increased bird abundance. The rate of bird predation was positively related to the abundance of insectivorous birds as well as to caterpillar abundance, which indicates that birds were able to respond to caterpillar density. We were not able to demonstrate a direct negative effect of bird predation on caterpillar abundance and a positive effect of caterpillar abundance on leaf damage. Structurally heterogeneous forests, however, suffered from less leaf damage than did homogeneous forests, which result may indicates that the higher activity of insectivorous birds in heterogeneous stands resulted in lower activity of insect herbivores. Thus, we concluded that forest management can contribute to the mitigation of insect damages by maintaining the suitability of forest stands to the insectivorous bird communities through the maintenance of high stand heterogeneity and the presence of some key elements (e.g. retention tree groups, tree diversity, shrub layer).

1. Introduction

Natural ecosystems supply human beings with an array of ecosystem services, without which civilization could not survive (e.g. Sekercioglu, 2010). In addition to their importance in maintaining the health of the ecosystems, most of these services also have a clear economic value (MEA, 2005). One of these economically important services is natural pest control (e.g. Takekawa and Garton, 1984; Kellermann et al., 2008). By consuming pests, natural enemies may act as regulators of pest populations, which may result in the reduction of plant damage (e.g. Sanz, 2001), and thereby reducing economic loss (e.g. Mols and Visser, 2007).

The potential role of natural enemies in the agricultural production has long been recognized. Less attention has been paid to the natural control of forest pests even though forest pests, especially leaf consuming insects, provoke severe damage for forestry worldwide every year (ICP Forest, 2011). In 2005, e.g., herbivorous insects defoliated over 16 million ha of forests in Canada alone (Chang et al., 2009). The situation is similarly serious in Europe, where the proportion of trees with moderate (more than 25%) defoliation has generally covered more than 20% of deciduous forests, and has shown a clearly increasing trend (UN-ECE/FAO, 2000). Over the last ten years, the most severely damaged areas have been the Mediterranean and the temperate deciduous oak forests of Central and Eastern Europe (ICP Forest, 2011), where caterpillars are the main defoliators. Their leaf consumption may decrease the growth of trees, negatively influencing their health condition, fecundity, and inhibiting regeneration (Rieske and Dillaway, 2008). The economic value of the wood losses due to reduced growth increases

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exponentially with the extent of defoliation (Reis et al., 2012), and may reach 310 $/ha/year (Lyytikainen-Saarenmaa and Tomppo, 2002). On top of these significant economic losses, regular insect outbreaks may trigger decline chains in the forests resulting in mass tree mortality (McManus and Csóka, 2007; Jepsen et al., 2013). Predicted climate change scenarios for Europe foresee more frequent and more severe forest insect outbreaks (Csóka, 1997).

To prevent this large-scale damage, different pest management tactics have been implemented, ranging from non-intervention to area-wide suppression by insecticides (e.g. Zolubas and Ziogas, 2006). In spite of some successful campaigns, it is practically impossible to suppress defoliators over large geographic region by chemical applications (Liebhold, 2012), mainly due to the considerable annual costs (Xue and Tisdell, 2001) and the undesired environmental consequences of pesticide application (Carson, 1962). The recognition of these drawbacks and the increasing public awareness against pesticides has drawn the attention to the role of natural enemies.

The main predators of caterpillars in forests are passerine birds (Kristin and Patocka, 1997), especially during the breeding season, when the proportion of caterpillars in the nestlings' diet can exceed 90% (Seki and Takano, 1998). During the rearing period, a Great Tit (*Parus major* L.) pair preys on approximately 15–20 thousand caterpillars (Török, 1998). Such levels of caterpillar consumption may cause a 20–70% reduction in caterpillar population, indicating a key role of birds in the health of forest ecosystems. However, the abundance of forest birds is highly affected by local factors, especially by forest structure and naturalness (e.g. Fuller, 2003; Hewson et al., 2011). Consequently, the local habitat features and naturalness of forest ecosystems may influence the trophic interactions between birds and caterpillars. Although the relationship between forest structure and bird abundance (e.g. Freemark and Merriam, 1986; Sekercioglu, 2002; Rosenwald et al., 2011), as well as the predation of caterpillars by birds has been widely examined (e.g. Holmes, 1990; Mols and Visser, 2007), we lack knowledge on how the whole system of forest – birds – caterpillar damage functions and how the service birds provide can be maintained and improved.

In this paper we explored the relationships between the abundance of birds, the abundance of caterpillars, the rate of predation, leaf damage and the effect of forest structure on these processes in temperate deciduous forests. Examining heterogeneous and homogeneous forest stands in pairs, we assumed that heterogeneous forests maintain higher bird abundance than do homogeneous forests, which results in higher predation rate, lower caterpillar abundance and leaf damage. Analysing the examined stands in general (that is heterogeneous and homogeneous stands were pooled for this analysis), we tested the following hypothesis (Fig. 1A): (1) stand structure variables characteristic of natural forests have a positive effect on bird abundance and (2) through the increased bird abundance an indirect negative one on caterpillar abundance; (3) increasing bird abundance increases the predation pressure on caterpillars; (4) higher predation pressure results in lower caterpillar abundance; and finally (5) leaf damage is positively related to caterpillar abundance. The examination of these relationships between the elements of forest ecosystems is needed to adapt the best management to maintain and improve processes which, in turn, provide ecosystem services.

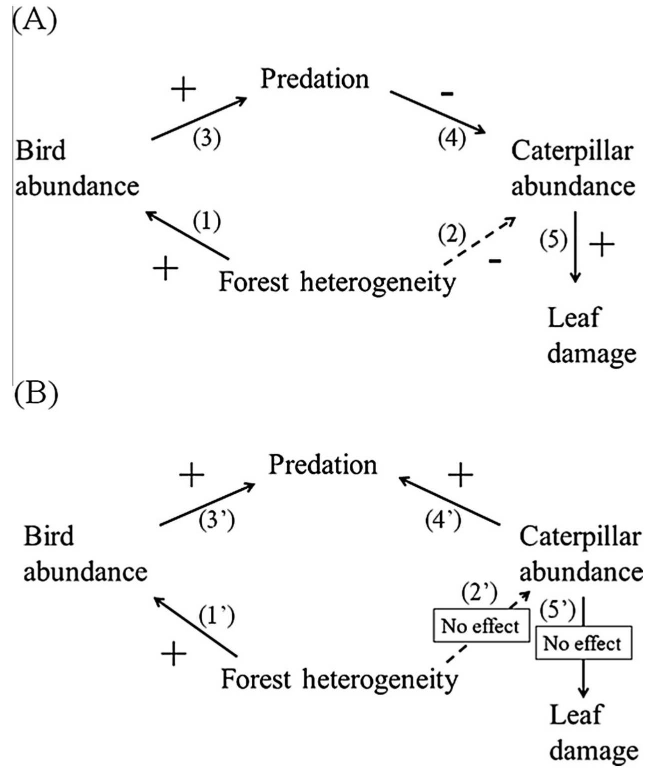

Fig. 1. The hypothesized effects of the studied system in temperate oak forests (A), and the effects between the elements according to our results (B). The arrows show the direction of the hypothesized and the detected effects between the elements of the studied system. The different arrow types represent direct (solid line) or indirect (dashed line) interactions. + indicates positive effect, – indicate negative effect, while no effect means no significant effect was found. The tested hypotheses were the following: forest heterogeneity increases bird abundance (1) and decreases caterpillar abundance (2), predation rate is positively related to bird abundance (3), increased predation rate decreases caterpillar abundance (4) and caterpillar abundance positively affects the leaf damage (5). The effects between the elements according to our results in temperate oak forest in Hungary: forest heterogeneity increased bird abundance (1′) but had no effect on caterpillar abundance (2′), predation rate was positively related to bird abundance (3′) and to caterpillar abundance (4′), leaf damage was not affected by caterpillar abundance (5′).

2. Materials and methods

2.1. Study site and experimental design

The experiment was carried out in the southern part of the Mátra Mountains (exact locations are given in Shapiro and Báldi, 2012), in northern Hungary in 2011. The elevation of the study area is between 400 and 500 m a.s.l.; the topography consists of slopes and narrow valleys. The climate is temperate with a mean annual temperature of 9 °C and an average annual precipitation of 600 mm (Dövényi, 2010). The most common soil type is brown forest soil on an andesite bedrock. This region is covered by deciduous forests dominated by sessile oak (*Quercus petraea* (Matt.) Liebl.) and turkey oak (*Q. cerris* L.), which are the two economically most important tree species across the study area with a mixture ratio of 90% (75% of sessile oak and 15% of turkey oak). The insect herbivorous guild of oaks is extremely rich in species in Hungary. As far as is currently known, more than 650 herbivorous insect species feed on oaks, and more than half of them are folivore (unpublished data of Csóka). Among folivore insects, 308 species belong to the Lepidoptera (Csóka and Szabóky, 2005). The monthly abundance of folivore species shows a clear seasonal pattern with a peak of early May or Mid-May, then decline continuously. Their species richness also has a characteristic seasonal pattern; however it peaks later, in late May and early June, and then shows a slow continuous decline. The spring/early summer folivore fauna in the sessile oak stands of mountainous regions is dominated mainly by Geometrid and Noctuid groups, while the late season fauna is dominated by more specialized groups such as leafminers and leafgallers (Csóka, 1998). Similar differences in folivore community