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Open-grown trees as key habitats for arthropods in temperate woodlands: The diversity, composition, and conservation value of associated communities

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ABSTRACT

Temperate open woodlands are recognized as biodiversity hotspots. They are characterised by the presence of scattered, open-grown, often old and large trees (hereafter referred to as "solitary trees"). Such trees are considered keystone ecological features for biodiversity. However, the ecological role of solitary trees and their importance for woodland communities are still not fully understood. Communities of arthropods in temperate forests are often structured not only by the horizontal openness of the stand, but also by vertical stratification. Thus there is a need for comparisons among communities associated with solitary trees and different forest strata. In this study, we analysed the diversity, conservation value, and nestedness of four taxonomic groups (beetles (Coleoptera), bees and wasps (aculeate Hymenoptera), ants (Formicidae), and spiders (Araneae)) on (i) *solitary trees* in open woodlands, and four habitat types in adjacent closed-canopy forests: (ii) *edge-canopy*, (iii) *edge-understorey*, (iv) *interior-canopy*, and (v) *interior-understorey*.

Across the focal insect groups, solitary trees harboured the greatest number of species, whilst spider communities were also equally rich in forest edge canopies. The conservation value of communities was highest in solitary trees for beetles, and in solitary trees and edge-canopy habitats for bees and wasps. For spiders, the conservation value was similar across all habitat types, but ordination analysis revealed general preferences for solitary trees among threatened species. We also found that communities from the forest interior were mostly only nested subsets of the communities found on solitary trees. Our results show an important and irreplaceable role that open-grown trees have in maintaining temperate woodland biodiversity. Therefore, preservation and maintenance of open-grown trees should be a primary concern in biological conservation.

1. Introduction

Open temperate woodlands host rich communities of plants and animals, including many endangered organisms (Bengtsson et al., 2000; Benes et al., 2006; Spitzer et al., 2008; Bergmeier et al., 2010; Hédl et al., 2010; Bugalho et al., 2011; Horak et al., 2014; Ramírez-Hernández et al., 2014). In Europe, they support a high biodiversity of tree-associated organisms. Evidence that a large proportion of European forests naturally occurred with open canopies for most of the Holocene has substantially increased in recent years (Vera, 2000; Whitehouse and Smith, 2004; Alexander, 2005; Birks, 2005). The open structure of these forests was formerly maintained by disturbances caused by fires or windthrows (Niklasson et al., 2010; Adámek et al., 2015; Hultberg et al., 2015), and by the grazing of large herbivores (Bengtsson et al., 2000; Vera, 2000). Since the mid-Mesolithic, these natural processes have been supplemented and later substituted by various human activities with a strong impact on woodland habitats. Slash-and-burn practices and later various silvopastoral management practices such as wood-pasturing and coppicing (Rackham, 1998; Szabó, 2009) have sustained the open structure of many European woodlands.

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The situation changed in the 18th century with the industrial and agricultural revolutions. Intensification of forestry management together with abandonment of traditional silvicultural practices led to a substantial increase in canopy closure, and consequently to a transition from open woodlands to closed-canopy mesic forests (Bürgi, 1999; Hédl et al., 2010; Kopecký et al., 2013). Today, open woodlands are scarce, fragmented, and still declining (Miklín and Čížek, 2014; Varga et al., 2015). Yet these open woodlands still host a rich, specialised community of arboricolous invertebrates (Dolek et al., 2009; Horak et al., 2014; Ramírez-Hernández et al., 2014).

A typical characteristic of open woodlands is the presence of scattered, open-grown, often large and old trees. Such trees are considered keystone ecological features for biodiversity in various temperate and boreal regions (Read, 2000; Manning et al., 2006; Fischer et al., 2010; Hall and Bunce, 2011; Lindenmayer et al., 2012, 2014; Siitonen and Ranius, 2015). Although these trees are referred to by various synonyms, such as isolated trees, dispersed trees, pasture trees, paddock trees, and remnant trees (see Manning et al., 2006), here, we call them collectively "solitary trees", meaning trees with well-developed and separated tree crowns, growing in isolation from closed-canopy forests. Wide-crowned trees can only develop in open conditions, which were formerly common in wood-pastures (Plieninger et al., 2015a; Hartel et al., 2013), traditional fruit or chestnut orchards (Horak et al., 2013; Plieninger et al., 2015b), noblemen's hunting parks (Fletcher, 2015), and in coppice with standards woods (Altman et al., 2013). Today, solitary trees occur in remnants of these habitats (Varga et al., 2015; Plieninger et al., 2015a), as well as in game reserves, parks, and tree alleys (Horak et al., 2014; Jonsell, 2011).

Solitary trees in wood-pastures are important breeding sites for birds because they often develop hollows (Hartel et al., 2014). Horak et al. (2014) found solitary trees were particularly attractive for saproxylic beetles since deadwood exposed to the sun is warmer, which enhances larval development. On the other hand, some groups of organisms, such as fungi or lichens, were found to be similarly rich at the edges of closed canopy forests (Horak et al., 2014). Moreover, in temperate forests the richness of arthropods often depends not only on the horizontal openness of the stand, but also on vertical stratification (Floren and Schmidl, 2008; Ulyshen, 2011), which can result in significant differences in communities between canopy and understorey strata. Therefore, regarding the conservation of woodland biodiversity, the question is to what extent forest edges or forest canopies can substitute for the role of fully open-grown trees. There is a need to explore communities from these habitats separately and then to compare them with solitary trees.

The aim of this study is to examine the ecological role of open-grown, solitary trees in maintaining temperate woodland biodiversity in comparison with closed-canopy forests. We compare the species density, composition, and conservation value of arthropod communities found on solitary trees with the communities found in the canopy and understorey at the forest edge and in the forest interior. We focused on four arthropod groups with a wide range of life-histories: beetles, bees and wasps, ants, and spiders.

2. Material and methods

2.1. Study area

This study was conducted in alluvial woodlands in South Moravia, Czech Republic (48°45′-48°50′N, 16°45′-16°55′E, alt. 160–170 m a.s.l.), within the floodplain of the lower Dyje (Thaya) river. The flat landscape is composed of managed hardwood forests and meadows with old solitary trees. The prevailing trees are pedunculate oak (*Quercus robur*), narrowleaf ash (*Fraxinus angustifolia*), hornbeam (*Carpinus betulus*), field maple (*Acer campestre*), limes (*Tilia cordata*, *T. platyphyllos*), European white elm (*Ulmus laevis*), poplars (*Populus alba*, *P. nigra*), and black alder (*Alnus glutinosa*). Historically, the local forests were managed as coppice with standards woods or pasture woodlands. These practices were abandoned 60–150 years ago in favour of growing high forest with a 90–150 year rotation (Vrška et al., 2006). These forests are mainly even-aged oak, ash and poplar plantations, wooded meadows with open-grown oaks, and occasional remnants of coppice with standards or pasture woodlands. The forests transitioned from mainly open woodlands to closed canopy stands from the mid 19th to the mid 20th century (Miklín and Čížek, 2014). The entire area is rich in saproxylic organisms, forming a hot spot within the Czech Republic and Central Europe (Rozkošný and Vaňhara, 1995, 1996).

2.2. Focal groups and sampling design

We sampled four groups of arthropods: beetles (Coleoptera) associated with deadwood and living trees (except for Staphylinidae; see Parmain et al., 2015), bees and wasps (Hymenoptera: Aculeata, except ants) nesting or foraging on trees, ants (Hymenoptera: Formicidae), and spiders (Araneae).

We sampled arthropods on solitary (open-grown) trees in wooded meadows and in a mature, closed-canopy forest that was formerly managed as coppice with standards. Coppicing was abandoned more than 60 years ago, and the stands have gradually transformed into high forests. The standards were already removed from the sampled patches, but the forest grew before the first clear-cut harvest. It thus retained continuity, high tree species richness and structural diversity.

Arthropods were sampled using flight interception traps composed of two crossed transparent polycarbonate sheets (25×50 cm) suspended above a collecting jar containing a saturated salt solution as a preservation liquid. A drop of liquid detergent was used to break the surface tension. Although flight interception traps are not the best method for collecting ants and spiders, we consider our collection of these groups to be adequately representative. Ants and spiders must crawl onto the trap to be caught (winged ant specimens were removed from the data), so their presence in our samples signified the utilization of particular trees.

The traps were installed on solitary trees (6–14 m above ground, mean 9.6 m), and in the canopy (14–26 m above ground, mean 20.3 m) and understorey (2–4 m above ground, mean 3.2 m) of the forest edge and interior. Each sampling site thus consisted of five different habitat types: (i) *solitary tree*, (ii) *edge-canopy*, (iii) *edge-understorey*, (iv) *interior-canopy*, and (v) *interior-understorey*. The DBH of solitary trees ranged from 410 to 680 cm (mean 513 cm), while trees at the edge ranged between 50 and 390 cm (mean 192 cm) in DBH, and trees in the forest interior ranged in DBH from 30 to 320 cm (mean 179 cm).

Sampling in the canopy and understory was undertaken in the same plots. Forest interior plots were established 36–88 m (mean 56.6 m) from the nearest forest edge plots. Solitary trees do not grow to great heights, which meant that we could not suspend traps at similar heights to that in the canopy in our closed forest sites. They also could not be suspended lower as numerous beetle collectors visit the site and often interfere with traps within their reach. However, our trapping design should have little effect on our results since previous work in this system showed very little difference between insect assemblages sampled above seven meters (Weiss et al., 2016).

Eight sampling sites were located 1–8 km apart. Altogether, we had eight replicates for each of the five habitat types, with 40 traps in total. The traps were exposed from 30th April to 2nd September 2006 and emptied every two weeks.