Forest Ecology and Management 402 (2017) 186–193

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Investigating the biodiversity of the forest strata: The importance of vertical stratification to the activity and development of saproxylic beetles in managed temperate deciduous forests

Radosław Plewa[a], Tomasz Jaworski[a], Jacek Hilszczański[a], Jakub Horák[b,*]

[a] Forest Research Institute, Department of Forest Protection, Braci Leśnej 3, Sękocin Stary, 05-090 Raszyn, Poland
[b] Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences, Department of Forest Protection and Entomology, Kamýcká 1176, CZ-165 21 Prague, Czech Republic

ARTICLE INFO

Keywords:
Forest canopy
Functional group
Functional trait
Guild
Oak stands
Red-list index

ABSTRACT

Saproxylic beetles represent an important part of the chain of decay processes and are of high interest for understanding the main drivers of forest community succession.

The main aims of this paper were to determine (i) the differences between communities of the crown and stem strata and (ii) the effect of fine vertical stratification within the studied strata on adult saproxylic beetle activity and the success of larval development.

The study was performed over three years in mature oak-dominated managed forests in Poland. The activity and development of the beetles was evaluated based on sampling from 60 traps and 60 logs, respectively.

In total, 11,237 individuals representing 364 species of saproxylic beetles were trapped and 388 individuals representing 38 species were reared. Compared with most previous studies, our results indicated that the majority of dependent variables (the species richness and abundance of saproxylic beetles and their functional groups, sub-guilds, and conservation-related and functional traits) revealed a significant preference for the crown, specifically the lower part. For example, predators searched for the transition zone between the crown and stem, which has a high prey density. The preferences of guild specialists and threatened species indicated that micro-habitats (e.g., hollows or fungi) are more frequent in the crown stratum than in the stem in managed forests, and the higher biomass of saproxylic beetles likely reflects the amount of energy produced in lower parts of crowns.

Compared with that observed in previous studies, the opposite pattern of preference for crowns was likely related to the higher anthropogenic pressure in managed forests, which is an important insight that can inform the future management (e.g., biocontrol by natural enemies or conservation) of these forest types.

1. Introduction

Forests are unique ecosystems because of the layer of tree species, and they are the last biotic frontier on Earth. The stems of mature trees and the large area of leaves, twigs, branches and limbs in the canopies are of great interest because, together with the soil, they compose the most ecologically important and biologically diversified environment in the world (André et al., 1994).

Influence of some environmental factors is relatively unpredictable, but information about their effect and the degree of human influence is increasing (Niklasson et al., 2010; Veblen et al., 1994). For example, the combination of bark beetle outbreaks and herbivory as well as the subsequent decay processes are of great interest in forest ecology (Schowalter, 1989; Terborgh et al., 2001; van Bael et al., 2003; Horak et al., 2014). The decomposition of wood, which is the dominant form of forest biomass, is important for understanding the main drivers and processes that lead to the formation of forest communities in ecosystems, including forests and woodlands under human influence. Furthermore, these processes are specific to different forest strata (e.g., the forest floor, stems, lower canopies or crowns of mature trees) because of disparate competitive relationships, such as the high abundance of herbivores in the crowns that are potential prey for predators, or abiotic factors, such as differences in humidity.

A number of studies have surveyed forest canopies, which are currently an active topic of research, and significant ecological insights have been gained (Floren et al., 2014; Leather et al., 2011; Ulyshen,

* Corresponding author.
E-mail address: jakub.sruby@gmail.com (J. Horák).

http://dx.doi.org/10.1016/j.foreco.2017.07.052
Received 17 May 2017; Received in revised form 27 July 2017; Accepted 29 July 2017
0378-1127/

2011). Crowns are known to be important to biodiversity (Bouget et al., 2011; Floren and Schmidl, 2008; Röder et al., 2010), and most studies have been performed in forests of high conservation value (Floren et al., 2014; Vodka and Cizek, 2013) that have not been seriously impacted by modern forestry. Nevertheless, vast areas of forests that are highly important to the timber industry are located in Europe, North America or the Far East, where forests that are managed for conservation or neglected forests still represent marginal areas. Moreover, the crowns in managed forests likely have high biodiversity potential.

Based on biodiversity indices (such as species richness), most recent studies have indicated that forest canopies do not represent a specific type of habitat for saproxylic beetles, which indicates that crowns are not significantly different from other aboveground forest habitats (Floren et al., 2014; Foit, 2010; Gossner et al., 2013a; Vodka and Cizek, 2013; Wermelinger et al., 2007). Several studies of canopy fauna have compared at least two levels of stratification (Birtele and Hardersen, 2012; Gossner and Ammer, 2006; Ulyshen and Hanula, 2007; Ulyshen et al., 2010), but to our knowledge, only a few studies have assessed the insects in the fine vertical stratification of the lower forest stratum and crowns (Basset et al., 2003). Furthermore, few studies have investigated managed forests, a neglected type of land use (Porter-Bolland et al., 2012).

Additionally, few studies have assessed the response of particular insect functional groups and guilds and their functional and conservation-related traits in human-induced temperate deciduous forests (e.g., Gossner et al., 2013a). Regarding functional groups, most studies have focused on the activity of vertebrate predators (Kalka et al., 2008; van Bael et al., 2003), and only a few have evaluated arthropods (Schowalter, 1989). With respect to human-induced forests, the diversification and changes of arthropod functional groups following cutting increases nutrient translocation from foliage (Schowalter et al., 1981), so the top-down effects of high trophic-level species leads to higher ecological stability in forest ecosystems. However, this stability is not strictly related to forest canopies (Terborgh et al., 2001). The influence of forest strata on specialized groups (such as sub-guilds of saproxylic beetles) has seldom been directly studied with most of the related research only partly focusing on saproxylic beetles and their activity in crowns. For example, Bouget et al. (2011) found variations among the guilds of stems and crowns in different forest types. The conservation-related and functional traits of saproxylic beetles have been poorly studied (Gossner et al., 2013b), and the influence of vertical forest stratification on these traits is not well known (Ulyshen, 2011).

We assessed the biodiversity indices (species richness, composition and abundance), functional traits (body length), conservation-related traits (red-list index), functional groups (cambium feeders, predators, mycophages and scavengers) and sub-guilds (fresh and rotten dead wood, cavity and fungi specialists) of one ecologically important guild of saproxylic beetles in managed oak forests in Poland. Our objectives were as follows:

(i) Determine whether forest crown and stem strata are significantly different;
(ii) Determine whether vertical stratification has a fine-scale effect in particular forest strata.

2. Materials and methods

2.1. Study area

The study was performed from 2009 to 2011 in oak-dominated managed forests in five forest districts in Poland (Fig. 1). We studied managed broadleaved forests, and the study sites were dominated by Pedunculate oak (*Quercus robur*) with an admixture of European hornbeam (*Carpinus betulus*) and two common conifers in Poland, the Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*). The studied forests were mature and aged between 115 and 169 years.

2.2. Dependent variables

The activity of saproxylic beetles was evaluated based on trap sampling (the experiments were performed in 2009–2010). In each of the five study sites, we selected 12 oaks spaced at least 50 m apart. Half of the traps were installed in the crowns of living trees (mean height: 20.57 m ± 0.50 SE), and the remainder (which were paired with the crown traps) were placed in the stem layer of the forest adjacent to the trunks of the tree (4.50 ± 0.21 m). We selected trees under more open canopy conditions (gaps) to better capture the activity of saproxylic beetles (Müller et al., 2015). To increase the trapping efficiency, we used original trap designs consisting of a combination of Malaise and Moericke traps; yellow pans were connected to a fine white net. In the first year, we used a trap that consisted of a bottle covered with a two-sided black roof to collect the insects (Fig. 2a), but due to the vulnerability of the roofs to wind, the traps were improved in the second year by replacing the black roof with a white net (Fig. 2b). The traps were placed in the same location each year. To preserve the collected insects, a mixture of water and ethylene glycol (1:1) was used in each trap, and a small amount of detergent was added to reduce the surface tension. The traps were emptied and refilled with preservative solution every 3–4 weeks.

The development of saproxylic beetles was studied based on rearings from logs sampled in 2011. In general, the experimental design was similar to that for the traps, and 60 logs were sampled (i.e., 12 logs in each of the 5 sites; one log was sampled from the crown and one from the stem of each tree). Logs (0.5 m in length) that showed no signs of colonization by the larvae of saproxylic insects were cut from the crowns of freshly felled oak trees and placed in the same locations as the traps in the spring; they were removed in the autumn to avoid damage from woodpeckers. In each study site, logs were exposed for the same period of time (ca. 133 days), and they were left outdoors for the winter to break the diapause of the overwintering stages of the insects within. They were then placed in separate rearing bags made of fabric, and a plastic container half-filled with a solution of ethylene glycol (1:1) was attached to collect the emerging insects.

In addition to often used species richness, composition and abundance indexes, the saproxylic beetles were also divided into four functional groups: (i) cambium feeders that consume the bast and/or wood, (ii) mycophages that forage on mycelia and/or fungi, (iii) predators that forage on other animals and (iv) scavengers that feed on detritus. Furthermore, four saproxylic guilds of species that live in (i) rotten wood, (ii) tree cavities, (iii) fresh wood and (iv) the fruiting bodies of wood-inhabiting fungi were included. Conservation-related traits were analyzed based on Polish red-listed species categories (Pawłowski et al., 2002) using a ranked value for each category: 5 for extinct species (EX), 4 for critically endangered species (CR), 3 for endangered species (EN) and 2 for vulnerable species (VU). A value of 1 was assigned to species considered data deficient (DD), most of which were rare species (Nieto and Alexander, 2010), and species of least concern (LC) were assigned a value of 0. Finally, we analyzed functional traits of the species using body length as indicated in recent Polish entomological literature; the body length of a species was multiplied by the number of individuals in each trap.

2.3. Study environmental variables

To control for the effect of dead wood and stand volume in a particular study forest, we estimated the amount of dead wood using the method of Czerepko (2008) with minor modifications. In each study site, the dead wood 7 cm in diameter and greater was measured within two 50 × 100 m rectangular sample plots (5000 m^2) and then extrapolated to an area of 1 ha. The volume of living trees was evaluated based on the diameter at breast height (DBH) and height.