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Effects of a host tree on movement and distribution of winter geometrid moths (Lepidoptera): thickness of trunks and branches

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Abstract

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Adult moths from an ecological group of winter geometrid species look for trees where they copulate and females lay eggs. We investigated how tree trunk and lower branch thickness affects the occurrence of females on trunks and branches and how the density of females and tree trunk thickness affects the occurrence of males on trunks. The research was carried out in a xeric thermophilous oak forest in southern Slovakia (Central Europe) in the winter season 2014–2015. The moths were obtained from *Quercus pubescens* trees by sticky bands. Three autumn species *Operophtera brumata*, *Erannis defoliaria*, *Alsophila aceraria* and four spring species *Agriopis leucophaearia*, *Agriopis marginaria*, *Apocheima hispidaria, Phigalia pilosaria* were recorded. We have found out that females had not exclusively negative geotactic behaviour as they (except for the rare *P. pilosaria*) occurred also on lower branches. Tree trunk and lower branch thickness had a positive effect on abundance of females of the three most abundant species (*A. leucophaearia, O. brumata*, *E. defoliaria*) on trunks and lower branches. Tree trunk thickness had a positive effect on density of the females of *A. leucophaearia* on trunks but not on *O. brumata* and *E. defoliaria.* The abundance of the males of *O. brumata*, *E. defoliaria* and *A. leucophaearia* on trunks was positively affected by tree trunk thickness and the density of their females.

Key words

behaviour, forest pests, phytophagous insects

Introduction

Species from an ecological group of winter geometrid moths (Geometridae) (Wahlberg et al., 2010) belong to the most important forest defoliators. The adults occur in the cold part of year (late autumn or early spring) and their brachypterous females are incapable of flight (Wahlberg et al., 2010). Their caterpillars are mostly polyphagous and form an important part of spring caterpillar assemblages (Patočka et al., 1999). *Operophtera brumata* is a well known winter moth species and has been the object of many ecological and behavioral studies (Cuming, 1961; Mrkva, 1968; Edland, 1971; Holliday, 1977; Tikkanen et al., 2006; Elkinton et al., 2014). Other winter moth species, although relatively abundant in Central Europe (Macek et al., 2012), have been much less studied.

After dusk, the virgin females of *O. brumata* climb tree trunks upwards (negative geotaxis) where they copulate. Then they continue crawling up trunks and lay their eggs in tree crowns (Mrkva, 1968; Graf et al., 1995; Van Dongen et al., 1998). The eggs are placed on branches (Mrkva, 1968; Holliday, 1977; Nilssen et al., 2007;

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Tenow et al., 2007) and sporadically on trunks (Mrkva, 1968; Watt et al., 1992). Mrkva (1968) discovered that on tall oaks the females preferred branches in the upper parts of trees. Also Graf et al. (1995) described the same preference on apple and cherry trees, although they recorded a considerable amount of females crawling on horizontal branches. The winged males fly around trees using vision and actively search for pheromone-emitting females (Mrkva, 1968; Van Dongen et al., 1994, 1998; Meyer-Rochow and Lau, 2008). We have not found similar detailed information about the behaviour of other winter geometrid species in the literature.

The aim of this study is to address the following questions: (1) What is the composition of assemblages of winter geometrid moths in a Central European xeric thermophilous oak forest? (2) Are the brachypterous females of winter moths negatively geotactic on low branched oaks? (3) How does tree trunk and lower branch thickness affect the total number of females on trunks and branches? (4) How does tree trunk thickness affect the density of females on trunks? (5) How do the density of females and tree trunk thickness affect the abundance of males on trunks?

We expected several species of winter moths in late autumn and early winter (referred to as autumn species in this study) and several species in late winter and early spring (referred to as spring species in this study) (cf. Patočka et al., 1999; Patočka and Kulfan, 2009; Macek et al., 2012). We supposed that all recorded species of this group of moths would have the same or similar behaviour because of specific winter conditions. We expected that some females could leave a tree trunk and climb branches in the lower parts of a host tree. This is also related to the distribution of eggs (Moravskaja, 1960; Graf et al., 1995). The total number of females could be higher on thick tree trunks and branches than on thin ones (Mrkva, 1968; Connell, 2013). Density of females could be higher on thick tree trunks than on thin ones if they are supposed to orient themselves by vision and to prefer thick tree trunks (cf. Grison and Silvestre de Sacy, 1954; Graf et al., 1995; Meyer-Rochow and Lau, 2008). Besides tree trunk thickness, abundance of males could also be affected by the density of pheromone-emitting females.

Materials and methods

Characteristics of the locality

The research was carried out in the southern part of the Western Carpathians, in the Krupinská planina Plateau in Slovakia, Central Europe (48°10'0.19''N, 18°59'46.08''E), at the altitude between 265 and 330 m asl. The area belongs to a warm climatic region with mean annual air temperature 8–9 °C and mean annual precipitation 600–700 mm (Anonymus, 2015b). Data were collected in a xeric thermophilous oak forest dominated by pubescent oak (*Quercus pubescens*) and Turkey oak (*Q. cerris*). Other tree species such as *Acer campestre* L., *A. tataricum* L., *Tilia* spp., *Sorbus torminalis* (L.) Crantz., *Crataegus* spp., *Carpinus betulus* L., *Pyrus* spp. and *Ulmus* spp. were infrequent and less abundant. The average height of oaks between 8–12 m is a result of warm and dry climate and dry shallow stony soils in the area. The age of trees is about 70 years and the average tree diameter at breast height is 20.4 cm. Surrounding landscape is managed extensively (sheep pastures, vineyards, fruit orchards, gardens) but the forest is without active management recently.

Data collecting

Forty-five trees of *Quercus pubescens* with a first lower branch growing from the trunk in an approximately right angle (90°) were selected. At each tree, trunk thickness (diameter) at breast height (DBH) and lower branch circumference at a distance of 10 cm from the trunk were measured. The range of distances of the lower branches from the ground surface was 55–200 cm. Moths were collected on the aforementioned 45 trees using sticky bands (Hébert and St-Antoine, 1999) (a product by Bio Plantella). One sticky band was installed on the first lower branch of the trees at a distance of 10 cm from the trunk. Another sticky band was placed on the trunk above the marked branch (Fig. 1). To avoid removal of glued moths by predators (mainly birds) we installed aviary mesh around all sticky bands. Adult moths were collected in the cold period from 20th November 2014 to 10th April 2015. During that time sticky bands were regularly controlled and replaced with fresh ones in order to avoid their saturation by moth males. After removing sticky bands with glued moths from trees we wrapped them into plastic wrap which enabled their easy handling, transport and storage in a refrigerator. Then the moths were determined and counted in a laboratory. We used a stereo microscope and identification guides Macek et al. (2012), Rennwald and Rodeland (2002), Jonko (2014) and Mazzei et al. (1999). The nomenclature follows Pastorális et al. (2013).

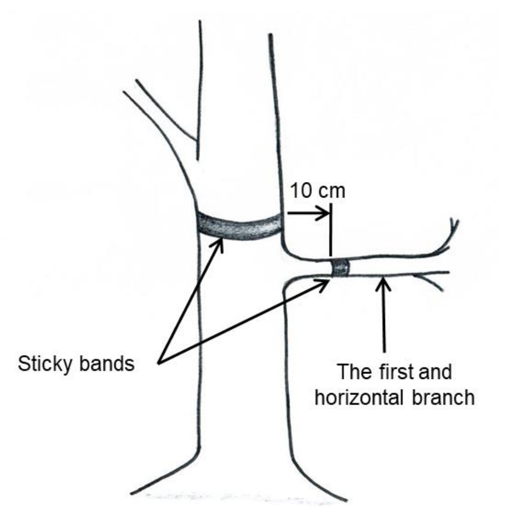

Fig. 1. Collecting of moths by sticky band method.

Statistical analysis

Moth abundance and density were modelled as a function of DBH and in case of males also as a function of the density of females. The abundance of moths was overdispersed, therefore, negative binomial model approach with log or square root link was used. In case of moth density models an offset variable, circumference of tree trunk at breast height, was incorporated. All analyses and figures were calculated in R (R Core Team, 2018) using mainly *MASS* (Venables and Ripley, 2002) and *visreg* (Breheny and Burchett, 2017) libraries.

Results

Using sticky bands, we recorded seven species in two time periods. Species caught in November and December 2014 (6,075 specimens) belonged to the group of autumn species and species caught in January–April 2015 (15,617 specimens) belonged to the group of spring species (Table 1). Among autumn species *O. brumata* and *E. defoliaria* dominated while among spring species only *A. leucophaearia* was dominant (Table 1). There were less females than males caught on sticky bands. The females of each autumn species (*O. brumata*, *E. defoliaria*, *A. aceraria*) comprised about 1/10 of all recorded specimens. Proportion of females of spring species was higher; the females of *A. leucophaearia* and *A. marginaria* comprised about 1/6 and those of *A. hispidaria* comprised more than 1/5 of recorded specimens (Fig. 2). *Phigalia pilosaria* (not shown in the Fig. 2) was rare; only four females and no males were recorded on tree trunks.

Table 1. Dominance of recorded winter geometrid species in a xeric thermophilous oak forest in southern Slovakia

Autumn species	Dominance (%)
Operophtera brumata (Linnaeus, 1758)	75.06
Erannis defoliaria (Clerck, 1759)	23.01
Alsophila aceraria (Denis et Schiffermüller, 1775)	1.93
Spring species	
Agriopis leucophaearia (Denis et Schiffermüller, 1775)	98.00
Agriopis marginaria (Fabricius, 1776)	1.74
Apocheima hispidaria (Denis et Schiffermüller, 1775)	0.23
Phigalia pilosaria (Denis et Schiffermüller, 1775)	0.03

The nomenclature by Pastorális et al. (2013) is used.

All species occurred on tree trunks and six species (*O. brumata*, *E. defoliaria*, *A. aceraria*, *A. leucophaearia*, *A. marginaria*, *A. hispidaria*) were also caught on the lowest branches. Nevertheless, most specimens were recorded on trunks above the first branches. Among the recorded species, males of *O. brumata* and both sexes of *A. hispidaria* occurred on branches most frequently (Fig. 2).

Tree trunk thickness (DBH) and branch thickness had a positive effect on female abundances of the three most abundant species – *O. brumata*, *E. defoliaria* and *A. leucophaearia* (Figs 3, 4) ($p < 0.05$ for all three species).

Density (number of specimens per 2 cm of tree trunk circumference at 1.3 m above ground level) of females was affected positively by tree trunk thickness only in the spring species *A. leucophaearia* ($p = 0.016$) (Fig. 5, c). Tree trunk thickness had no effect on density of females of the two most abundant autumn species – *O. brumata* and *E. defoliaria* (Fig. 5, a–b).

Abundance of males of the three most abundant species recorded (*O. brumata*, *E. defoliaria*, *A. leucophaearia*) was affected positively by tree trunk thickness ($p < 0.05$ for all three species) and by density of their females ($p < 0.05$ for all three species; Fig. 6, a–c).

Discussion

Adult geometrid moths collected from autumn to spring in season 2014–2015 represented the majority of winter moth species living on oaks in Central Europe (Kulfan, 1992; Patočka et al., 1999; Patočka and Kulfan, 2009; Macek et al., 2012). Among recorded autumn species *O. brumata* and *E. defoliaria* dominated markedly. These two geometrid moths belong to important defoliators with a tendency toward population outbreaks and high possibility of causing total defoliation (Mrkva, 1968; Ciornei and Mihalache, 1998; Patočka et al., 1999; Zúbrik, 2007; Neţoiu et al., 2014) and thus, their dominance in the studied oak forest stand was expected. Among spring species *A. leucophaearia* had the highest prevalence. Although it is abundant in Central Europe (Patočka, 1954; Szabó et al., 2007; Anonymus, 2015a), it has been omitted in forestry practice so far. The rest of the recorded species had low abundances although some of them can be numerous in some years or regions (cf. Csóka, 1998; Szabó et al., 2007; Neţoiu et al., 2014).

In the obtained samples females of all species comprised less than one quarter of all recorded specimens (except the rare *P. pilosaria*). This disproportion may be caused by different mobility between sexes. Males able to fly move easier within a tree and between trees. We suppose, therefore, that they stick easier on sticky bands. On the contrary, brachypterous females have limited motion as they are only able to walk, thus, less of them will stick on sticky bands. Besides that, males are attracted by female pheromones (Szöcz and Tóth, 1978; Roelofs et al., 1982; Szöcz et al., 1993; Van Dongen et al., 1998; Meyer-Rochow and Lau, 2008) and thus, females caught

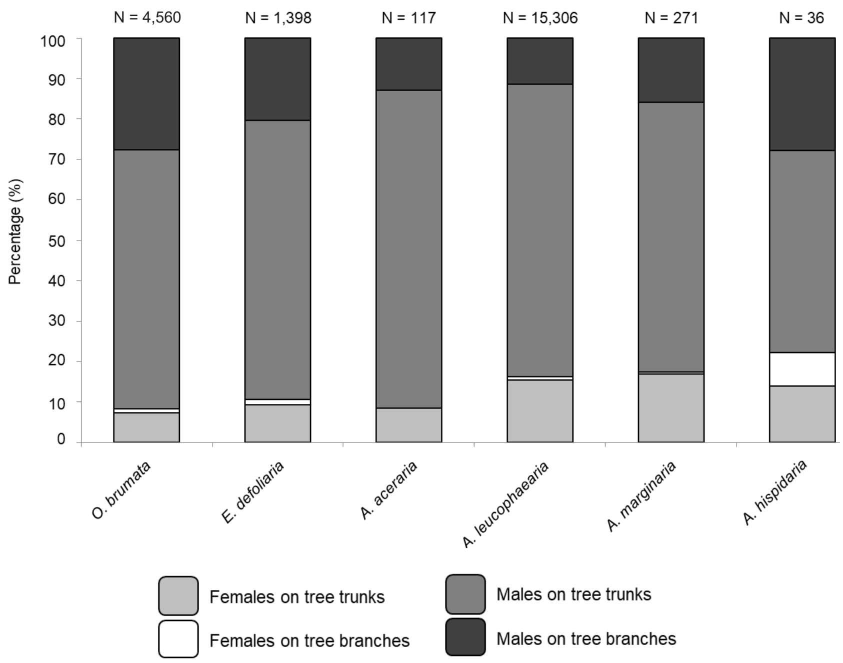

Fig. 2. Males and females of winter geometrid species caught on sticky bands on tree trunks and lower branches.

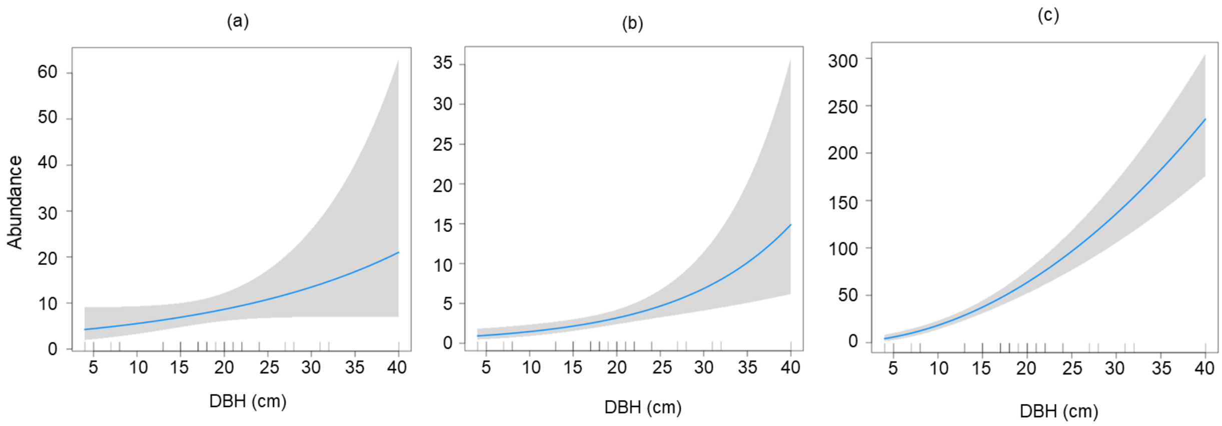

Fig. 3. Abundances of females of a) *O. brumata* ($p = 0.0411$; $X^2 = 4.174$), b) *E. defoliaria* ($p < 0.0001$; $X^2 = 21.165$) and c) *A. leucophaearia* ($p < 0.0001$; $X^2 = 47.356$) on tree trunks depending on tree trunk thickness (DBH).

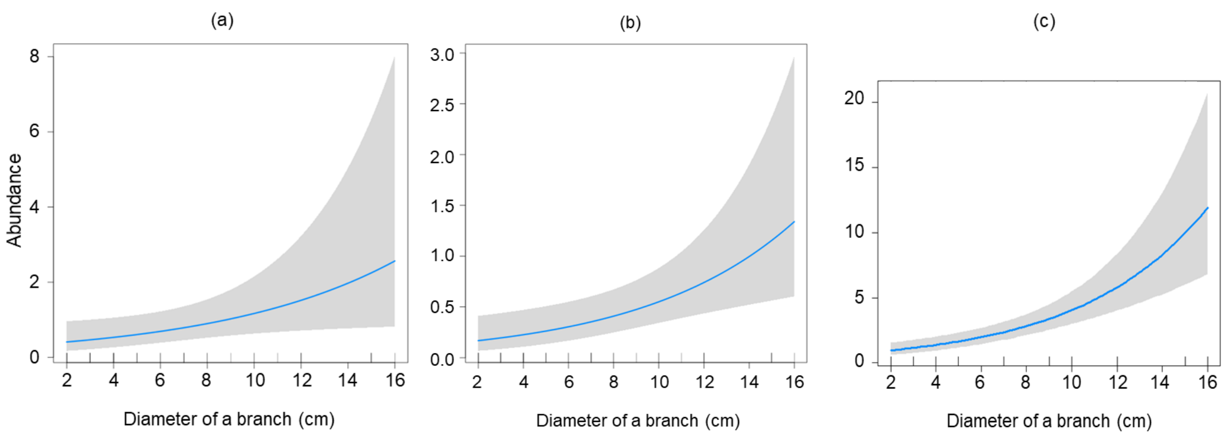

Fig. 4. Abundances of females of a) *O. brumata* ($p = 0.0196$; $X^2 = 5.449$), b) *E. defoliaria* ($p = 0.0034$; $X^2 = 8.573$) and c) *A. leucophaearia* ($p < 0.0001$; $X^2 = 33.254$) on lower branches depending on the thickness of these branches.

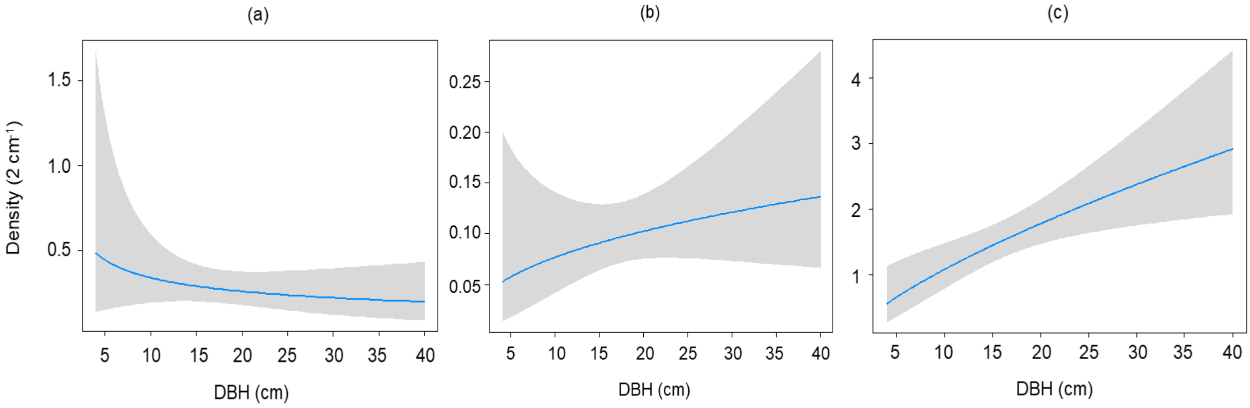

Fig. 5. Density (number of specimens per 2 cm of tree trunk circumference at 1.3 m above ground level) of females of a) *O. brumata* ($p = 0.341$; $X^2 = 1.060$), b) *E. defoliaria* ($p = 0.329$; $X^2 = 1.225$) and c) *A. leucophaearia* ($p = 0.016$; $X^2 = 7.311$) on tree trunks depending on the thickness of these trunks at 1.3 m above ground level.

on sticky bands could attract males continuously resulting in large numbers of captured males.

Specimens of both sexes occurred both on tree trunks and first lower horizontal tree branches (except *A. aceraria*). Tree trunk and lower branch thickness had a positive effect on the abundance of females of the three most abundant species – *O. brumata*, *E. defoliaria* and *A. leucophaearia*. This confirms results obtained on *O. brumata* by Mrkva (1968) and Connell (2013). This dependence had not been known before in the other two species. According to Parák (2015) tree trunk thickness measured at a place of contact with ground had affected female density of *O. brumata* and *A. leucophaearia* positively.

Females of *O. brumata* orient themselves in space by vision (Grison and Silvestre de Sacy, 1954; Graf et al., 1995; Meyer-Rochow and Lau, 2008). At the time of their eclosion from pupae and search for places for oviposition, the majority of trees and bushes are bare/without foliage. Thus, females do not elect a host plant (Connell, 2013) and climb every vertical object in their vicinity (Grison and Silvestre de Sacy, 1954; Graf et al., 1995). Despite the fact that the visual orientation has not been studied yet in the rest of the recorded species, we suppose, based on our results, that the females of *E. defoliaria* and *A. leucophaearia* orient themselves by vision, too, and climb all vertical objects, so they can colonise any tree in their vicinity.

In our study, about 1/10 of females of *O. brumata* and *E. defoliaria*, and 6% of females of *A. leucophaearia* were recorded on horizontal branches (Fig. 2). This means that females climbing tree trunks are not exclusively negatively geotactic and could perceive protruding branches in front of them. It suggests possible visual orientation in determining direction of their movement. Distribution of eggs of *O. brumata* (and therefore movement of females) differs between tree species (Moravskaja, 1960; Mrkva, 1968; Graf et al., 1995). Mrkva (1968) explained this contrast as a result of different bark structure between tree species. Another reason may be host plant architecture. For example, Mrkva (1968) reported that females of *O. brumata* almost avoided lower lateral branches on about 25 m tall trees of *Quercus robur*. In our study, some females changed direction from trunks to the first horizontal branches on low branched trees of *Q. pubescens* with similar bark. As many males were recorded on the first horizontal branches (Fig. 2), we suppose that the females reaching these branches can be fertilized there as well (or they are already fertilized) and subsequently oviposit. There is a variability of sources in tree crowns (shelters and food sources) (Gripenberg and Roslin, 2005) and therefore behaviour of females like this provides their offspring a good chance to find appropriate food sources of high quality.

The density of females was positively affected by tree trunk thickness only in the spring species *A. leucophaearia*. This factor had no effect on both autumn species *O. brumata* and *E. defoliaria*. The reasons are unclear. One explanation could be that *A. leucophaearia* has different visual perception in comparison with *O. brumata* and *E. defoliaria* and its females are more attracted by thick trunks. Another explanation could be larger stocks of pupae in the ground below thicker trees. Revealing the causes behind this requires further research.

Tree trunk thickness had also a positive effect on abundance of males in the three most abundant species (*O. brumata*, *E. defoliaria* and *A. leucophaearia*). This result suggests importance of vision (visual orientation) of males as Meyer-Rochow and Lau (2008) had shown for *O. brumata*. Besides this factor, female density affected male abundance positively, too. Like on branches, females attracted males by emitting pheromones on tree trunks (Szöcz and Tóth, 1978; Roelofs et al., 1982; Szöcz et al., 1993).

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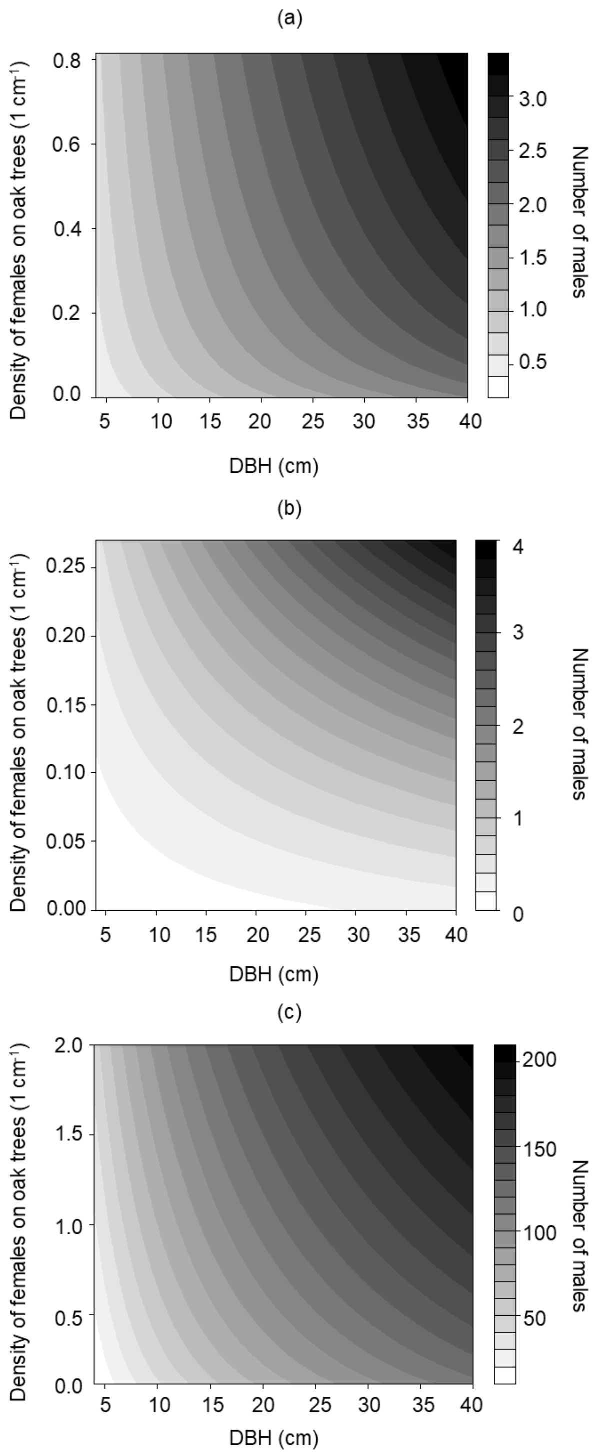

Fig. 6. Abundance of males on trunks of oak trees of a) *O. brumata* (factor female density: $p < 0.0001$, $X^2 = 16.2600$; factor trunk thickness: $p = 0.0176$, $X^2 = 5.6367$), b) *E. defoliaria* (factor female density: $p = 0.0118$, $X^2 = 6.3350$; factor trunk thickness: $p = 0.0138$, $X^2 = 6.0586$) and c) *A. leucophaearia* (factor female density: $p = 0.0120$, $X^2 = 6.3060$; factor trunk thickness: $p < 0.0001$, $X^2 = 51.0420$) depending on tree trunk thickness and density of their females (number of specimens per 1 cm of tree trunk circumference at 1.3 m above ground level).

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