

Article

Spatial Distribution of Lepidoptera in Forest Ecosystems of Central European Russia: Studies Using Beer Traps

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Abstract: Temperate forests are highly complex ecosystems in which many aspects of invertebrate distribution and abundance remain poorly understood. In order to accumulate data on the vertical and temporal distribution of forest Lepidoptera in the Republic of Mordovia (central European part of Russia), specimens were collected with beer-baited traps from April to October in 2019–2022. Traps were deployed at different heights above ground level (i.e., 1.5, 3.5, 7, and 12 m) in deciduous forests, pine forests, forest edges, and forest glades. Over the four-year sampling period, over 69,000 specimens of Lepidoptera were collected and examined. In deciduous forests, maximum abundance was observed at 12 m above ground level, whereas in pine forests, maximum abundance was observed at 7 m. In both forest types, the lowest abundance was observed at the lowest sample sites (i.e., 1.5 m above ground level). In forest glades in 2020, maximum abundance was observed at 2 m, with abundance showing a conspicuous decline with trap height above the ground. However, this pattern was not repeated in subsequent years. Lepidoptera exhibited various patterns of seasonal abundance among habitat types, but most showed bi- or trimodal patterns (corresponding with spring summer and fall), with the greatest number of specimens captured in late summer or autumn. Forest edges showed the greatest abundance of all sampled habitat types.

Keywords: insects; distribution; dynamics; number; Republic of Mordovia



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1. Introduction

Forests are three-dimensionally structured ecosystems where plant species and environmental resources are heterogeneously distributed in time and space [1–4]. Knowing how this three-dimensional heterogeneity affects the spatial and temporal distribution of invertebrates and vertebrates is important for designing conservation measures [5–9]. The forest canopy, as the top layer of vegetation formed by tree crowns, is a particularly important habitat and resource used by vertebrate and invertebrate forest animals [10–14]. The technical ability of researchers to access the canopy has made it possible to detect vertical stratification in forests, i.e., clear boundaries in communities across the entire vertical from the ground to the upper forest tiers [15].

The forest canopy in some forests is thought to contain most of the insect biodiversity [16–18]. The study of insect distribution reveals differences in biodiversity, species distribution, and biology (e.g., sex ratio/life stage). It is influenced by trophic level, habitat features, seasonality, and/or the aspect or direction (vertical/horizontal ones). The greatest number of Neuroptera species at five forest sites has been captured precisely in the crowns of trees [19]. However, there are many instances where the species diversity and abundance of insects was higher in the ground layer or in the understory [20–22]. For example, Giovanni et al. [23] showed that the major part of the Sphecidae community in the undergrowth consists of species that prey on bivalves and spiders. Apparently, differences in biodiversity and abundance of insects in the space depend on taxonomic group, microclimatic conditions of habitats, season, sex, developmental stage, and other reasons [21,24,25]. The sex ratio of Syrphidae differed significantly between the two strata,

as females were mainly caught at ground level, while males were predominantly caught in the canopy [26]. According to Duelli et al. [27], Neuroptera showed their highest species abundance in the shrub belt and in the canopy. Species abundance peaked in the canopy deep in the forest. Some species of Scolytinae (Coleoptera) were associated with traps deployed at 7 to 21 m, while other species were recorded at 1.2 m [28]. Vertical stratification of Chrysomelidae was more distinct in wet habitats than in dry ones [29]. Studies using ultraviolet light traps installed at various vertical levels in dipterocarp forest in Sarawak, Malaysia, showed that peak abundance was observed at canopy level (35 m) for some ecological groups of insects; for scavengers and aquatic predators, abundance was higher at the subcanopy level (25 m) [30]. Diptera, Hymenoptera, and Coleoptera were most abundant at ground level, while Lepidoptera and Heteroptera were more abundant at upper canopy levels [31].

In recent decades, there has been a significant increase in the number of ecological studies using bait traps for catching Lepidoptera, which can be used to study their spatial distribution [32]. Checa et al. [33] determined that the main Lepidoptera lines differed in their response to microclimate and microhabitat, which explained some pro-spatial differences in community structure. Furthermore, some of the most abundant species changed their microhabitat preferences during the dry season. Multidimensional scaling of Lepidoptera populations in forests on islands in Indonesia revealed various vertically and horizontally structured communities [34]. In Brazilian tropical forests, clear differences were found between canopy and understory with a significantly higher Lepidoptera abundance in the canopy. Two marked peaks of abundance and richness were also observed in both layers: one during the transition from dry to wet season and the other during the transition from wet to dry season [35]. In another study from Brazilian forests, the species composition of Lepidoptera also differed significantly between the two vertical layers, with higher species richness and abundance in the understory, but less diversity compared to the canopy. Species were heterogeneously distributed between understory and canopy in this forest with lower canopy height [36]. Species diversity of Lepidoptera in secondary forests in Tasik Kenyir (Malaysia) areas was higher at ground level than at canopy level. Lepidoptera composition has a high diversity at ground level compared to canopy level [37]. Observations by Schulze et al. [38] showed that beneath forest canopies there is a unique Lepidoptera fauna that differs from that of the ground layers. Lepidoptera biodiversity also varies in space, not only vertically, but also horizontally. For example, Lepidoptera diversity in naturally occurring lake edges is very different from the pasture–forest edge, and the distribution of species abundance in undisturbed and disturbed forested areas has significant differences [39].

In our study of the spatial distribution of Lepidoptera, we used beer traps, which are baited, easy to make, and have been used to study seasonal rhythms of abundance [40], height distribution [13], and post-fire insect fauna [41]. Our research objectives included: (a) study the vertical distribution of Lepidoptera in deciduous and pine forests; (b) study the vertical distribution in large glades; and (c) study the spatial distribution at forest edges.

2. Materials and Methods

2.1. Study Area and Design of Studies

All studies were conducted in the western part of the Republic of Mordovia in 2019–2022 (Temnikov District, Krasnoslobodsk District) (Figure 1). The Republic of Mordovia is located in the eastern part of the East European Plain. The western part is situated on the Oka-Don Plain, while the central and eastern parts are situated on the Volga Upland. The Republic of Mordovia is located among the Nizhny Novgorod region, Ulyanovsk region, Penza region, Ryazan region, and the Chuvash Republic.



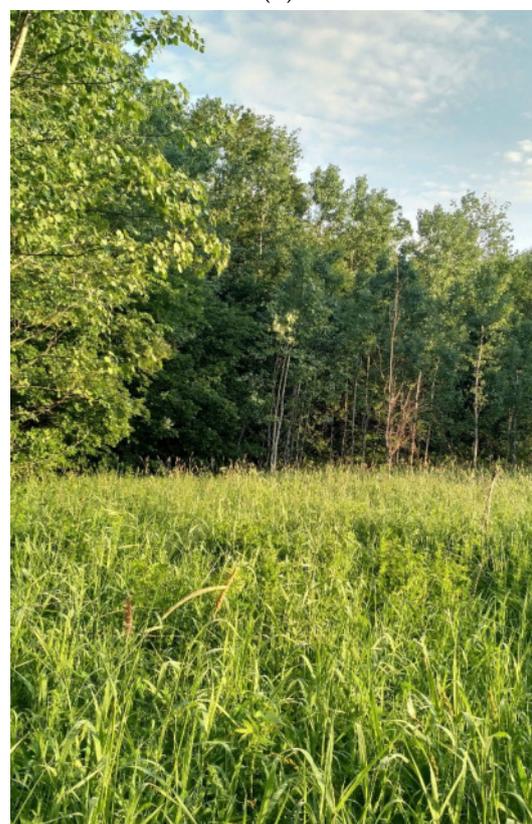
(a)



(b)



(c)



(d)

Figure 1. Photos of the study sites. Description of biotopes in the text: (a)—deciduous forest; (b)—pine forest; (c)—glade in the forest with a research installation; (d)—edge of deciduous forest (all photos made by A.B. Ruchin).

The climate is moderately continental. The western part of the Republic of Mordovia is located in a zone of coniferous–broadleaved and broadleaved forests, while in the central and eastern regions shrub and meadow steppes prevail [42].

Collections were made using traps of our own design. A five-liter plastic container with a window cut out on one side at a distance of 10 cm from the bottom was used as a trap [43,44]. Beer was used as bait. Sugar, jam, and honey were added in each case for fermentation. The period between checking the condition of the traps was from 5 to 16 days. Insects were checked, washed, and preserved in 70% alcohol. In the laboratory, the contents of the cans were disassembled and the number of individuals was counted.

(1) Vertical distribution in deciduous forests

Experiments were performed in five deciduous forest fragments (plots), each located at least 1.5 km from the other. In each plot we delineated one transect with four sampling points at various heights, spaced no more than 20 m from each other.

The field survey was carried out in a deciduous forest consisting of *Tilia cordata* Mill. (90% of the forest canopy layer) and *Quercus robur* L. (10%) with projective cover of 60%. The understory layer (projective cover: 70%) was represented by *Acer platanoides* L. (projective cover: 65%), *Ulmus glabra* Hudson. (10%), *Tilia cordata* (40%), and *Euonymus verrucosus* Scop. (solitary plants). The ground layer consisted of *Carex pilosa* Scop., *Mercurialis perennis* L., *Glechoma hederacea* L., *Asarum europaeum* L. Other species include *Aegopodium podagraria* L., *Stachys sylvatica* L., *Viola mirabilis* L., *Polygonatum multiflorum* (L.) All., *Pulmonaria obscura* Dum., *Geum urbanum* L., *Lathyrus vernus* (L.) Bernh., *Rubus holostea* L., *Equisetum sylvaticum* L., *Dryopteris filix-mas* (L.) Schott, *Paris quadrifolia* L., *Galium odoratum* (L.) Scop., and *Anthriscus sylvestris* L. The understory was very distinct, but the grass cover was thinned out due to the reduced amount of available sunlight. The studies were conducted from May to September 2020. A total of 172 samplings (exposures) were carried out.

(2) Vertical distribution in pine forests

The experiments were carried out in five pine forest fragments (plots), each at least 1.5 km from the other. In each forest fragment there were four sampling points at various heights, located no more than 20 m from each other.

The study sites were pine forests with green moss. The canopy layer consisted of *Pinus sylvestris* L. The understory layer was quite thin, being represented by *Betula pendula* Roth, and singular trees of *Picea abies* L. and *Populus tremula* L. In the undergrowth layer, the following shrubs were present: *Sorbus aucuparia* L., *Rubus idaeus* L., and *Frangula alnus* Mill. with a total percent cover of ca. 35%. The ground layer vegetation was dominated by *Convallaria majalis* L. with participation of *Calamagrostis epigeios* (L.) Roth. Other vascular plants of the ground layer include *Dryopteris carthusiana* (Vill.) H.P. Fuchs, *Fragaria vesca* L., *Melampyrum pratense* L., *Anthoxanthum odoratum* L., *Galium mollugo* L., *Agrostis gigantea* Roth, *Triantalis europaea* L., *Luzula pilosa* (L.) Willd., and *Calamagrostis arundinaceus* (L.) Roth. A total of 176 samplings (exposures) were carried out.

(3) Vertical distribution in clearings in forests

A special installation was used to perform these experiments. It comprises a hollow tube with a diameter of 72 mm and a height of 10 m from the soil surface (Figure 1). Every 2 m on this pipe there are crossbars on which insect traps are suspended. There were no barriers to species movement between the hanging traps. Insects were free to migrate along the height.

The studies were carried out in a clearing of 0.93 ha. The glade was bounded on the south side by a lake. To the north, west and east, there is a mixed forest border with *Pinus sylvestris*, *Quercus robur*, *Populus tremula*, *Picea abies*, *Tilia cordata*, *Betula pendula* and *Betula alba* L., *Alnus glutinosa* (L.) Gaertn. *Lonicera xylosteum* L., *Euonymus verrucosa* Scop., *Frangula alnus* grow in the understory. *Prunus domestica* L. and *Pyrus communis* L. grow on the border of the clearing and the forest near small wooden buildings. Perennial grasses in the clearing include *Carex praecox* Schreb., *Calamagrostis epigeios*, *Bromopsis inermis* (Leyss.)

Holub, *Elytrigia repens* (L.) Nevski, *Dactylis glomerata* L., *Veronica prostrata* L., *Acinos arvensis* (Lam.) Dandy, *Galium verum* L., *Galium mollugo*, *Achillea millefolium* L., *Erigeron annuus* (L.) Pers., *Fragaria viridis* (Duch.) Weston, *Conyza canadensis* (L.) Crong. also occur in the glade. *Verbascum thapsus* L., *Poa bulbosa* L., *Rumex confertus* Willd., *Alchemilla* sp. and other herbaceous plants are sporadically recorded. Studies were conducted from May to October 2020, from April to October 2021, and from May to October 2022. A total of 205 samplings (exposures) were carried out.

(4) The impact of the glades on the distribution

In the forest edge, there is sparse (canopy cover about 10%) birch herbaceous (*Betula pendula*). *Salix caprea* L., *S. cinerea* L., *Sorbus aucuparia*, *Frangula alnus*, and *Malus sylvestris* are present in the understory. Grass cover is represented mainly by light-loving and shade-tolerant species (*Leucanthemum vulgare* Lam., *Seseli libanotis* (L.) Koch, *Melampyrum nemorosum* L. and others). Weed species such as *Erigeron annuus*, *Cichorium intybus* L., and *Linaria vulgaris* L. were noted. The site in the depth of the forest is represented by a herbaceous birch forest with a higher projective cover (about 30–40%). The habitat is more humid than on the forest edge. Aspen (*Populus tremula*) is present in the understory. The shrub layer includes *Sorbus aucuparia*, *Frangula alnus*. The grass layer includes typical forest species (*Dryopteris carthusiana*, *D. expansa* (C. Presl) Fraser-Jenkins Et Germy, *Viola canina* L., *Fragaria vesca*, *Convallaria majalis*). Studies were conducted from May to August 2019, from May to October 2020, and from April to September 2021. A total of 190 sampling (exposures) were conducted.

2.2. Data Analyses

While analyzing the results, we used only the quantitative parameter (abundance) of all Lepidoptera in the traps for the exposure time. No special statistical methods were used. Identification to species of this group was difficult due to poor preservation and impossibility-to-identify material. Exposure time is the period between hanging a trap and taking samples for analysis (expressed in days). All data from individual plots were then averaged over the whole time of the experiments. A total of 69,309 Lepidoptera were captured and examined during the experiment.

3. Results

(1) Vertical distribution in deciduous forests

In deciduous forests, the highest cumulative Lepidoptera abundance for the season was at 12 m, the lowest at 1.5 m (Figure 2). At other heights, abundance values were intermediate.

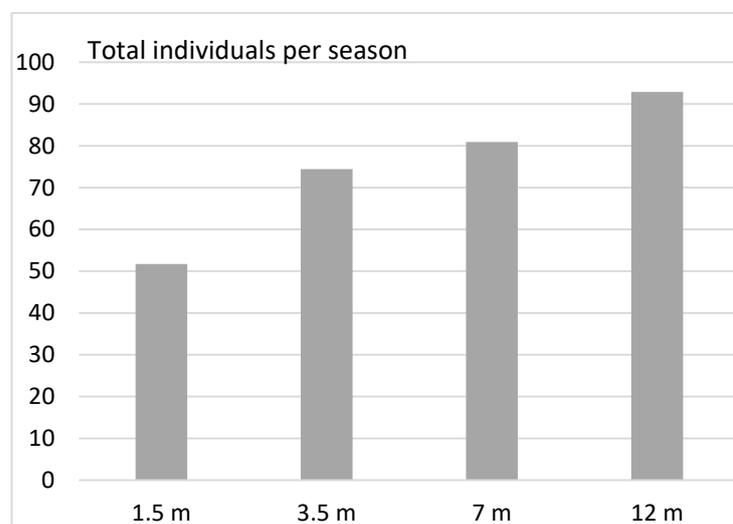


Figure 2. Lepidoptera total abundance at various heights in deciduous forests.

Lepidoptera abundance trends had a two-peak pattern at all heights in deciduous forests. The first small peak in abundance was obtained in mid-June. The second peak was obtained in the second half of July (Figure 3). The flight activity was similar at all heights. However, in September the abundance of Lepidoptera was significantly higher than in May.

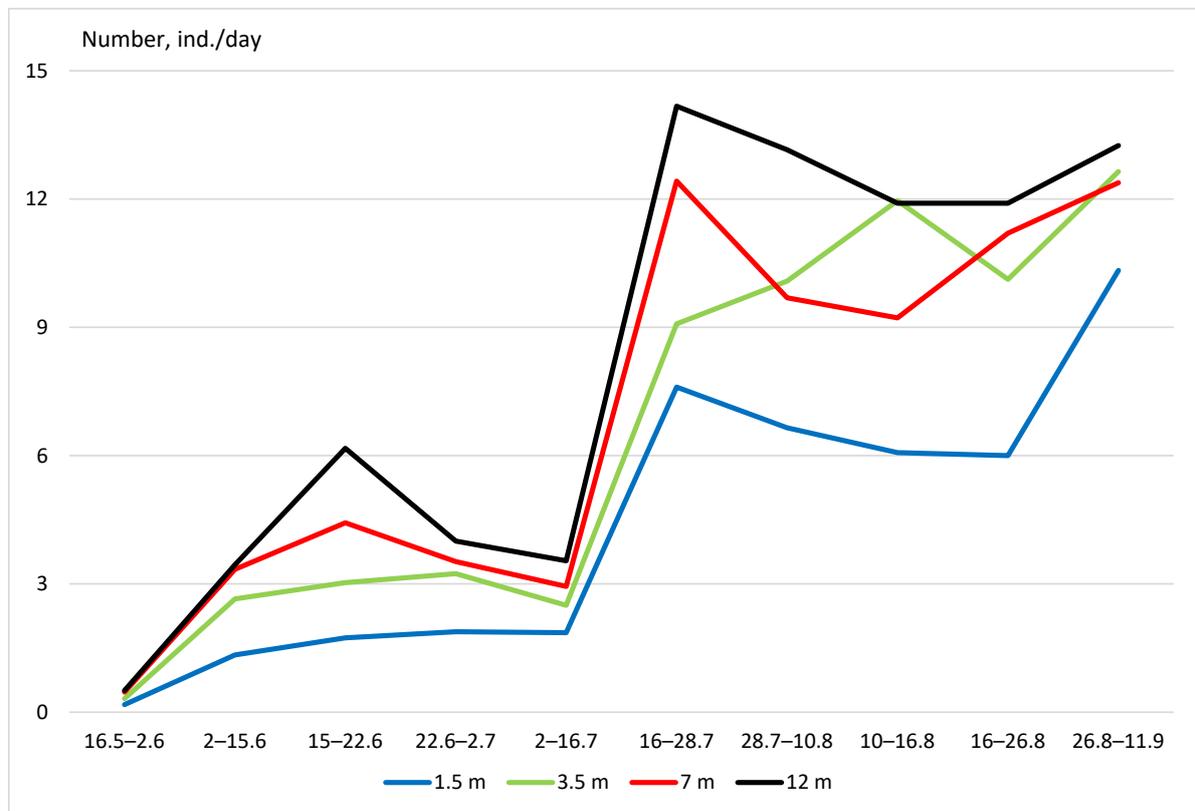


Figure 3. Seasonal dynamics of Lepidoptera abundance at various heights in deciduous forests.

(2) Vertical distribution in pine forests

In pine forests, the highest total Lepidoptera numbers for the season were obtained at 7 m, slightly lower numbers of Lepidoptera were recorded at 3 m, and the lowest numbers at 1.5 m (Figure 4).

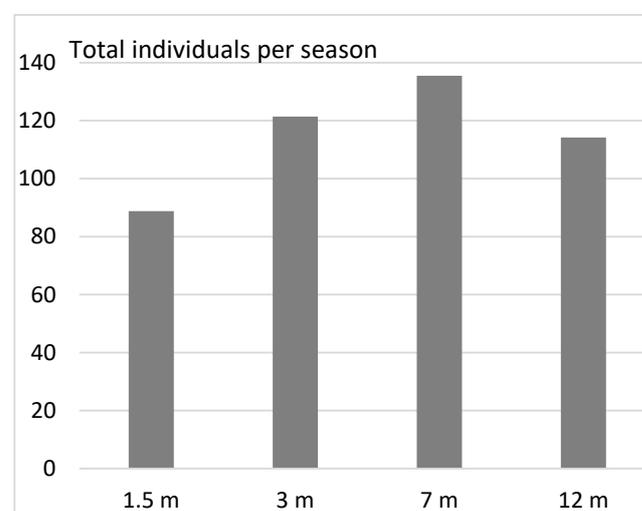


Figure 4. Cumulative abundance of Lepidoptera at various heights in pine forests.

In pine forests, Lepidoptera flight activity had three peaks: late May, June, and mid-July. In contrast to deciduous forests, numbers of Lepidoptera in September were not very different from those in May. At all heights, the flight activity was almost the same (Figure 5).

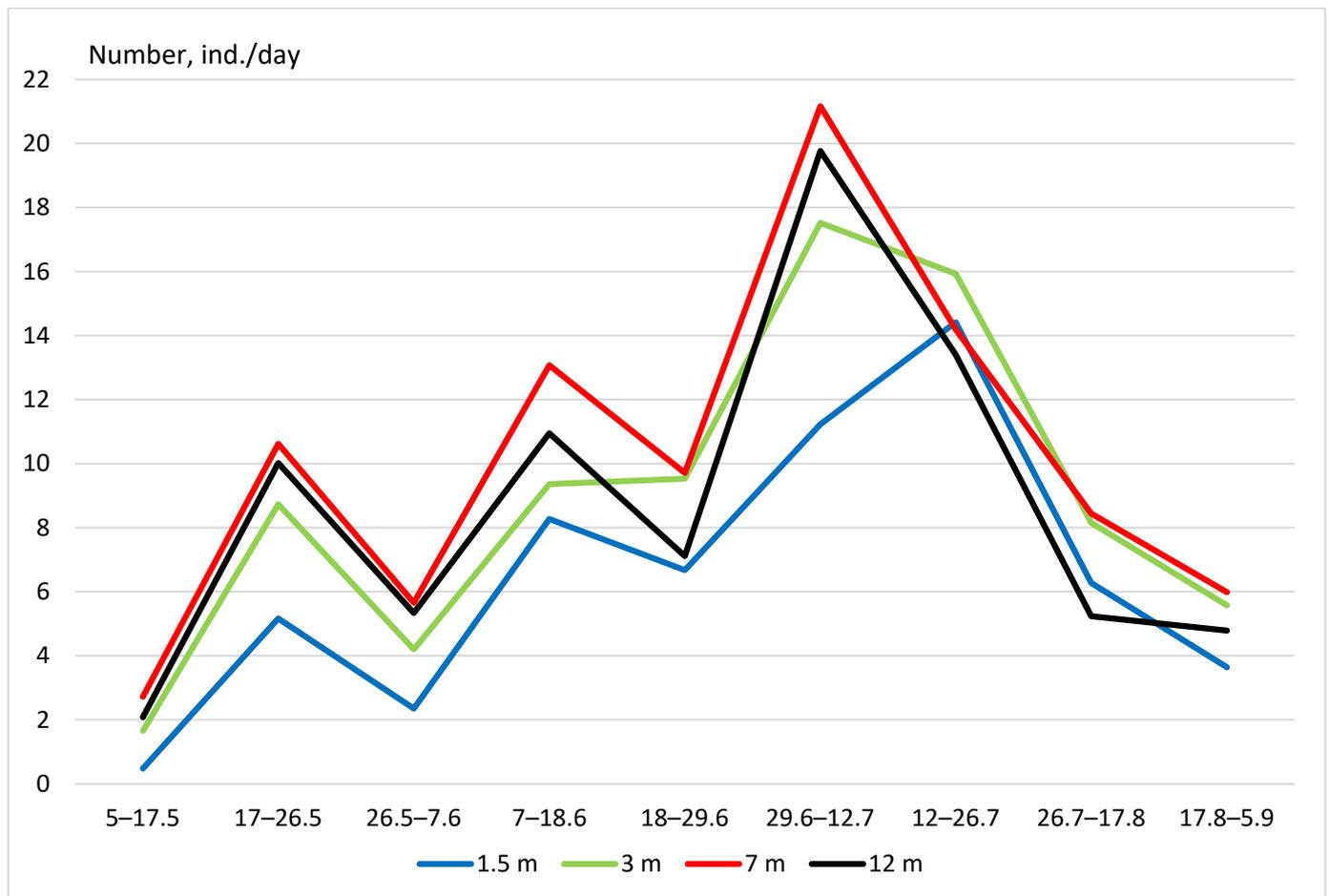


Figure 5. Seasonal dynamics of Lepidoptera abundance at various heights in pine forests.

(3) Vertical distribution in glades in forests

In contrast to forest ecosystems, in open habitats, the number of Lepidoptera had a completely different character at various heights. According to the studies of 2020–2022, the average number of Lepidoptera was higher at the 2 m height during the whole period of observations. The lowest number of Lepidoptera was found in the highest trap at 10 m. At other heights, abundance was intermediate (Figure 6).

In glades, Lepidoptera abundance had two peaks, which were recorded in mid-July and in late September–early October. As in closed biotopes, the flight activity at all heights was almost the same (Figure 7).

(4) The impact of glades on the distribution

The highest Lepidoptera abundance totals were obtained in marginal habitats (Figure 8). The traps below and above the edges had higher numbers of Lepidoptera than the traps in the forest interior.

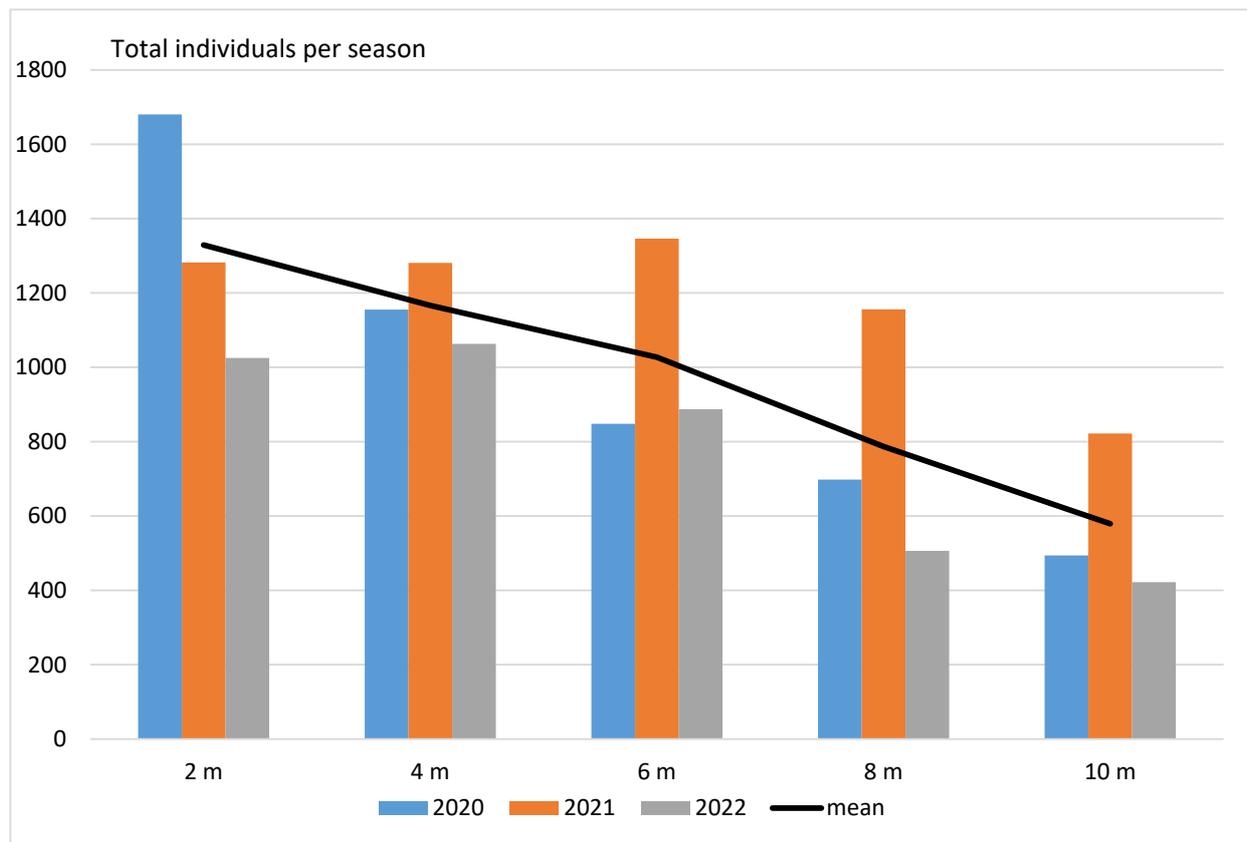


Figure 6. Cumulative Lepidoptera abundance at various heights in forest glades in 2020–2022.

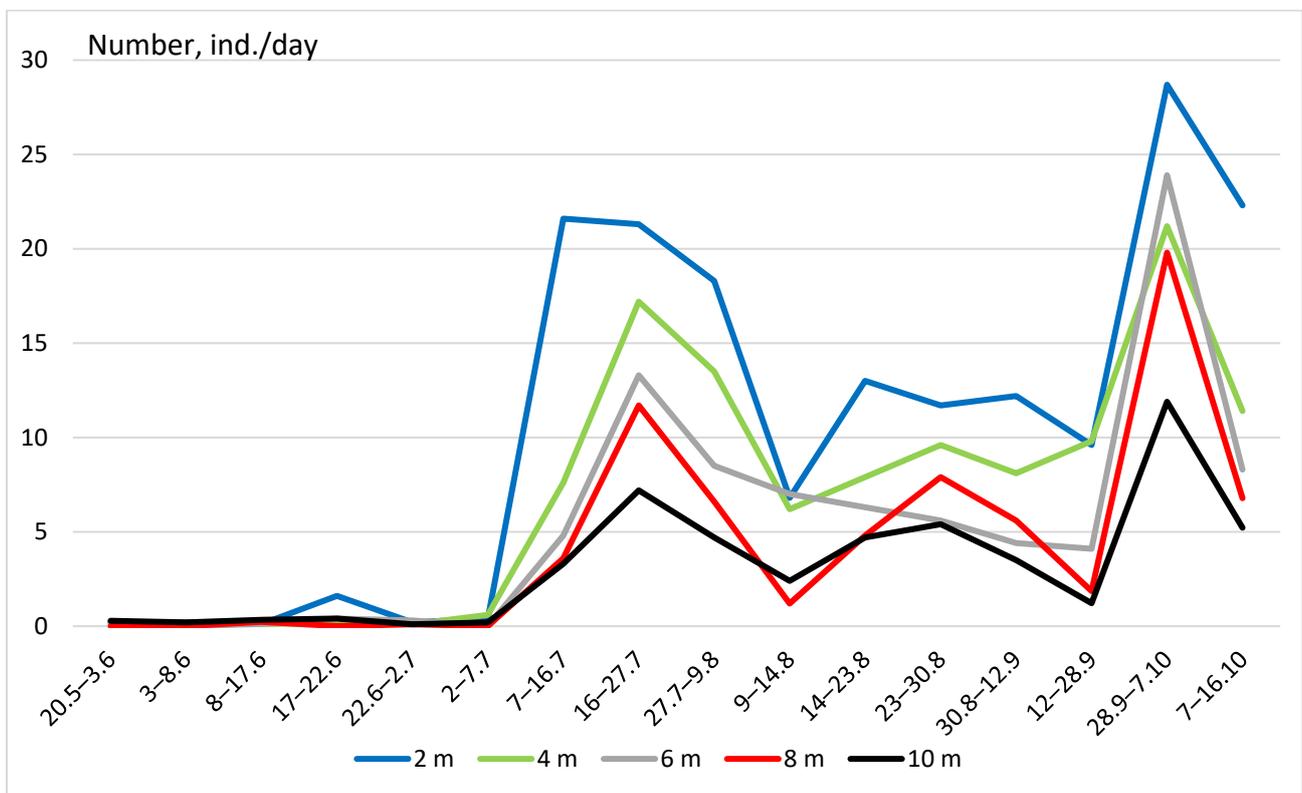


Figure 7. Seasonal dynamics of Lepidoptera abundance at various heights on forest glades in 2020.

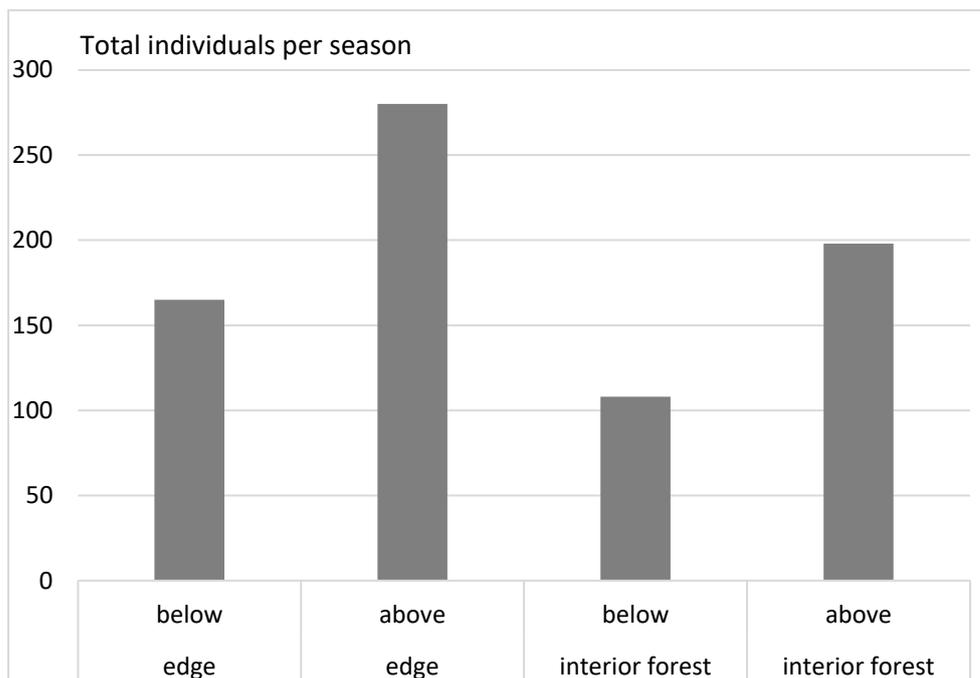


Figure 8. Lepidoptera cumulative abundance in glades and within the forest.

Lepidoptera abundance trends in glades had two peaks, which were recorded in the second half of July and in mid-September. As in other habitats, the flight activity in these experiments was similar (Figure 9).

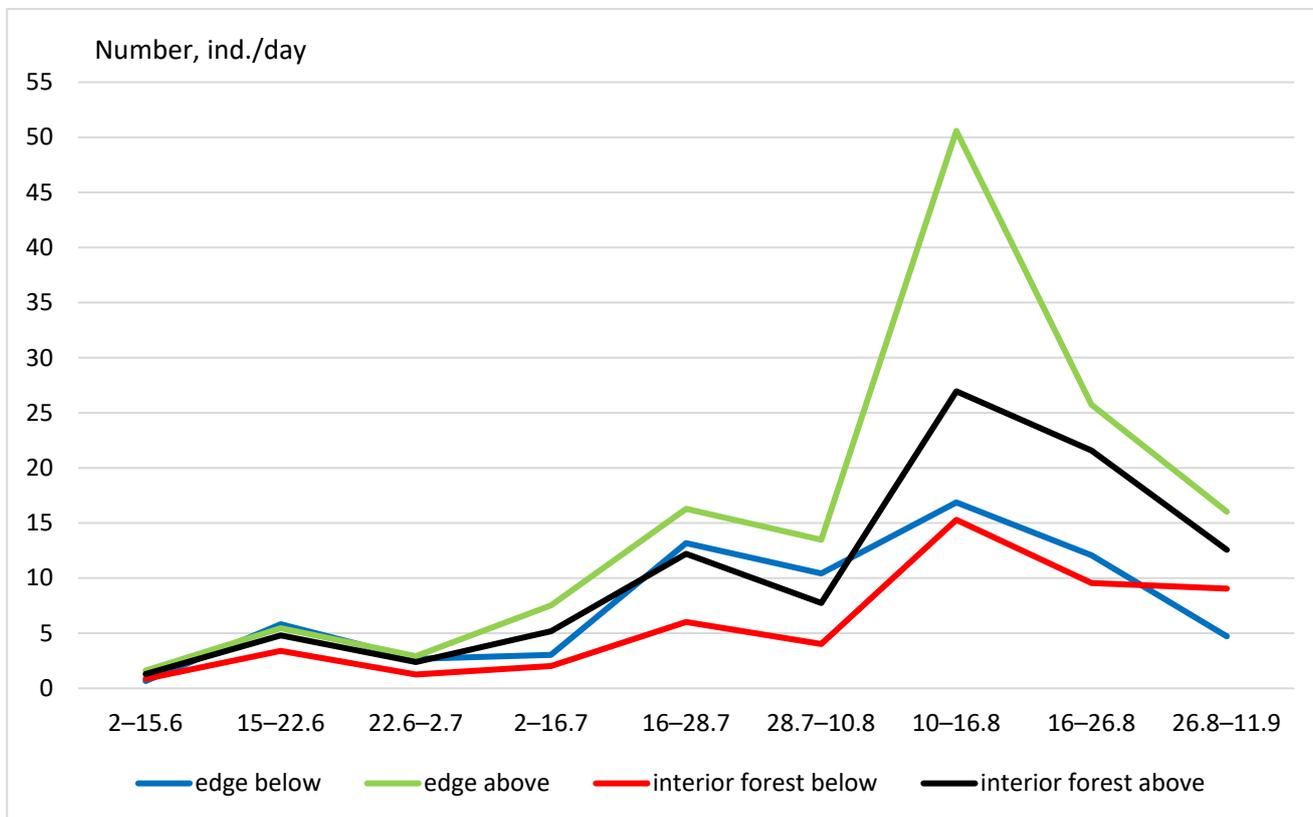


Figure 9. Seasonal abundance of Lepidoptera in edges and interior forest (at various heights).

4. Discussion

Various methods are used to study the spatial distribution of insects. In most cases, different trap designs are used, including those that can either passively trap insects (e.g., window traps) or attract them by using various chemical agents, as well as fruit [45,46]. Lepidoptera attracted by rotting fruit, digesting liquids, and fermenting baits are easily trapped [47,48]. Families of Lepidoptera are differentially attracted to various baits in traps. For example, Geometridae prefer ethyl alcohol, β -phenethyl alcohol, and acetone. In experiments, a mixture of eight compounds showed a synergistic increase in attractiveness for Thyatiridae and Noctuidae, but not for Geometridae [47]. Other researchers have also reported that fermented bait can be used as an attractant for Noctuidae insects [45,49]. Moreover, such baited traps can provide reliable estimates of the number of specimens caught [50]. In this study and previously [24,25], we have demonstrated that traps baited with beer and sugar were effective to study the vertical and spatial distribution of Lepidoptera in several habitats. The number of attracted individuals is quite large, and is suitable for use in various analyses of the spatial distribution of Lepidoptera along habitats [24], and to study the seasonal flight activity [25].

Studies on the vertical distribution of Lepidoptera in forests of various climatic zones have shown that there are non-uniform vertically distributed communities. Multiple factors determine such patterns [21]. The spatial distribution of Lepidoptera in forested and non-forested habitats also has some dependencies, which in many cases have yet to be studied more substantively [35,51]. For example, in many cases, results have been obtained showing increased biodiversity and abundance of invertebrates in the tropical forest canopy compared to the ground layer and understory [35,36,52]. Flying insects in the tropical forests of Panama, Papua New Guinea and Brunei were in some cases more abundant in the tree crowns [53]. However, the Lepidoptera family in the Costa Rican rainforest showed an increase in species diversity with height vertically, whereas the other family was vertically distributed in the opposite direction [54]. Lepidoptera in Borneo showed a decrease in abundance in the forest canopy compared to lower levels, which may be related to resource change [38]. At the same time, the distribution pattern of invertebrates is still poorly understood in temperate forest ecosystems.

In deciduous forests of central European Russia, we showed that the highest total Lepidoptera abundance for the season was at the highest level of trap installation (12 m), while the lowest abundance was observed at 1.5 m. At other heights, abundance values were intermediate. However, a different relationship was observed in pine forests. The highest total abundance of Lepidoptera was recorded at 7 m height, a slightly lower abundance of Lepidoptera at 3 and 12 m, and the lowest abundance at 1.5 m height. As we indicated in the biotope description, the forest canopy was rather closed in deciduous forests, and the grass layer was poorly distinct due to low sunlight transmission through the leaves of upper forest tiers [55,56]. It is likely that under these conditions (less foraging habitat for caterpillars, lower temperatures due to low insolation, high humidity) fewer species occur near the soil with low numbers of these Lepidoptera species.

In pine forests, on the contrary, sunlight penetrates well through the needles and the warming capacity of all tiers of this type of forest is approximately the same. Apparently, this results in high numbers of Lepidoptera under the forest canopy and in the shrub layer. At the same time, there are no deciduous trees in the forest canopy in pine forests, i.e., there is no forage base for Lepidoptera. Low numbers may be due to that fact. The grass layer in forests is not very well represented either due to the quality of soil, which in this case is sandy. Such soil is nutrient-poor and less fertile [57,58].

Forest edges are defined as the transition zone between open habitats and forests (ecotone). The edges of forests may differ considerably from each other. For instance, differences may be in the position of the edge in relation to the sun, differences in the width, density and shape of tree trunks, and differences in the species composition of trees and grass cover in open habitats. These changing environmental parameters affect the communities and abundance of arthropods in marginal areas [24,59–61]. Our study

examined the edges of deciduous forests. The highest Lepidoptera abundance totals were obtained at the forest/grassland boundary. Both downstream and upstream, the abundance of Lepidoptera was higher on edges than in the forest interior. It is well known that many Lepidoptera species prefer open, sunny edges [62–64].

Seasonal population cycles are well known for most insects [40,65–67]. In Lepidoptera, such cycles are known and are associated with seasonal changes in temperature, day length, humidity, and other factors. In tropical ecosystems, seasonal cycles depend on the mix of rainy and dry seasons [68–71], while in temperate forests seasonal variability is influenced by photoperiod and temperature [72–74]. In our study, the seasonal dynamics of Lepidoptera abundance were well defined. Lepidoptera flight activity had two or three peaks in forest ecosystems at all heights. In May–June, the first Lepidoptera appeared: their caterpillars wintered or appeared in spring. A second population maximum was obtained in July. At this time, many adult Lepidoptera are actively attracted to baits with fermented beer and sugar. The Noctuidae, Geometridae, Erebidae, Thyatiridae, and other families usually fly to these lures [47,50,75,76]. However, the general trend shows an increase in trap numbers in the second half of summer and autumn, while numbers in spring are very low. An interesting trend emerged where, in canopy habitats (pine and deciduous forests), the maximum abundance peak occurred in mid-July and September, respectively. However, in open habitats (glades), the maximum abundance was obtained in late September–early October. It is likely that this maximum abundance is related to the migration of Lepidoptera from forest habitats, where temperatures are lower at this time, to open habitats with apparently higher solar insolation and higher air temperatures [77]. Perhaps, nectar sources are also declining in the closed forest canopy. In addition, the temperature and food sources attract adults into the open areas.

5. Conclusions

Beer and sugar (fermented bait) traps are an effective system to study the spatial distribution of Lepidoptera in forest ecosystems. The vertical distribution of Lepidoptera abundance differed in deciduous forests and pine forests. In deciduous forests, maximum abundance was recorded at a height of 12 m, while in pine forests it was 7 m. In both cases, the lowest Lepidoptera numbers were found in the ground layer at 1.5 m height. There are some differences in the seasonal cycles of Lepidoptera numbers. There can be two or three peaks of the flight activity. Before these peaks, we recorded a decline in numbers. The general trend shows increasing numbers of trapped Lepidoptera in the second half of summer and autumn, while numbers in spring are very low. Forest edges seem to be areas of concentration for Lepidoptera in open and closed biotypes. Presumably, distribution of food resources, temperature, and air humidity influence the Lepidoptera distribution in forests and open biotopes. Further research should focus on the biodiversity of individual groups and families and their spatial distribution in temperate forests.

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