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Seasonal dynamics and spatial distribution of lepidopterans in selected locations in Mordovia, Russia

ALEXANDER B. RUCHIN
Joint Directorate of the Mordovia State Nature Reserve and National Park «Smolny», Russia.
e-mail: ruchin.alexander@gmail.com

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Abstract. *Ruchin AB. 2021. Seasonal dynamics and spatial distribution of lepidopterans in selected locations in Mordovia, Russia. Biodiversitas 22: 2569-2575.* The research was conducted in 2019-2020 in the Republic of Mordovia (European part of Russia). In order to collect Lepidoptera, beer traps were used where beer served as bait. The field surveys were carried out from April to October in various forest habitats. The air temperature was recorded. To elucidate the spatial distribution of Lepidoptera, various habitats were examined in two study plots. In total, more than 23 thousand Lepidoptera specimens were examined. The largest number of Lepidoptera was collected in oak forests in contrast to the four other forest habitats. In all habitats, population dynamics were similar and characterized by the same trends of decrease and increase. During the season, there were three peaks of abundance for this group. A moderate first peak was recorded in the second half of May, while the maximum peak occurred in the first half of July. Autumn population peaks depend on temperature, while spring and summer peaks are associated with the flight of imagos and an increase in the lepidopteran abundance in habitats. In open habitats, the abundance of Lepidoptera was lower. On forest edges, the number of Lepidoptera considerably exceeded one in open habitats (river sandbanks, willow thickets, forest glades, and floodplain meadows) and closed habitats (inside the forests). Forest edges are a hotspot of Lepidoptera abundance and biodiversity in forest habitats. According to the vertical gradient, the number of lepidopterans was higher at the height of 7.5 m than at the height of 1.5 m. At the lower height, the number of Lepidoptera did not vary as considerably as at higher heights.

Keywords: Butterflies, dynamics, insects, Mordovia, State Nature Reserve

INTRODUCTION

The spatial distribution of species and individual taxonomic groups among habitats has been studied for quite a long time (Chursina and Ruchin 2018; Cicort-Lucaciu 2020; Proshchalykin and Sergeev 2020; Sergeev and Makarkin 2021). For example, many studies were devoted to the vertical distribution of various insect groups (Sutton and Hudson 1980; DeVries 1988; Rubik 1993; Kirstova et al. 2017). In temperate forests, parasitic Hymenoptera is more abundant in the herb layer of the forests than at higher heights (Preisser et al. 1998). In other experiments, a considerable proportion of Vespidae specimens were caught by traps established in the forest crowns (Ulyshen et al. 2011). Giovanni et al. (2017) showed that in the undergrowth layer, most amount of the Sphecidae community consists of species preying on dipterans and spiders. The sex ratio of syrphids differed considerably between the two layers, as females were caught mainly on the ground, while males were caught mainly in the canopy (Birtele and Hardersen 2012). Some differences in the height preferences of Diptera were found during surveys using beer traps (Dvořák et al. 2020). Other studies indicated an increase in the Diptera abundance in the forest canopy (Maguire et al. 2014; Gossner et al. 2016; Krivosheina and Krivosheina 2019).

The largest number of Neuroptera species was caught in the tree crowns in five various forest areas (Gruppe and Schubert 2001). Saure and Klelhorn (1993) found 22 and 24 species in the crowns of pine and oak, respectively. According to Duelli et al. (2002), Neuroptera showed their highest species abundance in the glacier belt and in the crowns. In the forest depth, the species number peaked in the canopy. High level of Chrysopidae biodiversity has been identified in the tree canopy (Makarkin and Ruchin 2019). Some species of Scolytinae (Coleoptera) were associated with traps exposed at heights of 7-21 m, while other species were associated with heights of 1.2 m (Procházka et al. 2018). The vertical stratification of Chrysomelidae was more pronounced in wet habitats than in dry ones (Charles and Basset 2005; Sergeev 2020). The distribution of Cerambycidae beetles was dependent on the height (Graham et al. 2012). The abundance and biomass of Cetoniinae were higher in trap set at a height of 10.5 m. The abundance of Rutelinae is higher at a height of 4.5, 7.5 and 10.5 m (Puker et al. 2020).

There were clear differences in diversity and abundance of lepidopterans between canopy and understory in the rainforests of Brazil (Santos et al. 2017). Schulze et al. (2001) showed that under forest canopy there is a unique butterfly fauna that differs from the Lepidoptera fauna of the surface layers. In addition, the Lepidoptera biodiversity varies in space not only vertically, but also horizontally. Thus, the variety of Lepidoptera in naturally occurring lake edge is very different from the pasture-forest edge. The comparison showed that in natural and disturbed forest areas, the distribution of species abundance has considerable differences (Devries et al. 1999). For our studies of Lepidoptera, we used beer traps with baits, which have simple construction.

MATERIALS AND METHODS

Study area and field survey design

All studies were conducted in the Republic of Mordovia in 2019-2020 (Temnikov district, Mordovia State Nature Reserve and its immediate surroundings) (Figure 1). Mordovia State Nature Reserve is located on the right bank of the Moksha River and covers an area of 321.62 km^2. According to the natural zoning, the forest area of the reserve is included in the zone of coniferous-broad-leaved forests on the border with the forest steppe. Forest covers 89.3% of the total area. Pine (*Pinus sylvestris* L.) is the main forest-forming species in the Mordovia State Nature Reserve. It forms pure or mixed plant communities in the southern, central and western parts of the Protected Area. Birch (*Betula pendula* Roth) forests occupy the second rank of the forest-forming tree species in the Mordovia State Nature Reserve. These are mainly secondary communities in the areas of cuttings and burnt pine forests. Oak (*Quercus robur* L.) forests occupy a relatively small area of the Mordovia State Nature Reserve. They are common in the Moksha River floodplain in the western part. Spruce (*Picea abies* L.) forests and alder (*Alnus glutinosa* (L.) Gaertn.) forests are located mainly in floodplains of rivers and streams by occupying small areas. The main areas of floodplain meadows are located along the Moksha River in the southwest of Mordovia State Nature Reserve. The protected area borders the Nizhny Novgorod region in the north.

Collection of Lepidoptera specimens was carried out by crown 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 (Ruchin et al. 2020). Beer or wine was used as bait. For fermentation, sugar, jam, and honey were added in each specific case.

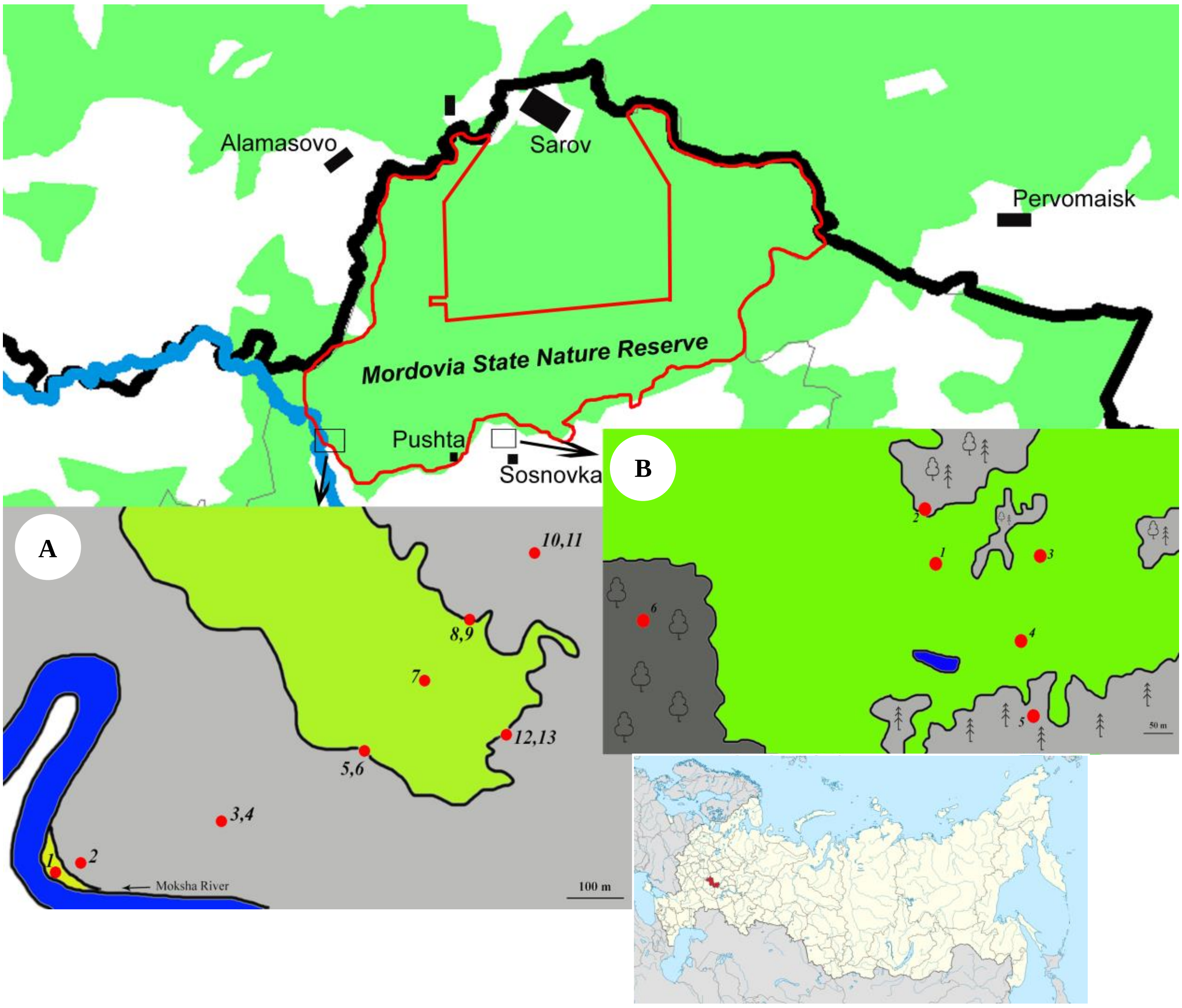

Figure 1. Research locations in the Mordovia State Nature Reserve, Russian Federation and its surroundings. Note: A. Surroundings of the cordon Taratinsky; B. Surroundings of the Sosnovka village

Seasonal experiments

To study seasonal dynamics, traps were placed in five various habitats (a detailed description of the habitats is given in Ruchin et al. (2021). The habitat was named by the prevailing tree species in them: 1 - the forest area with a predominance of *Pinus sylvestris* (pine forest); 2 - the forest area with a predominance of *Tilia cordata* (lime forest); 3 - the forest area with a predominance of *Populus tremula* (aspen forest); 4 - the forest area with a predominance of *Betula pendula* (birch forest); 5 - the forest area with a predominance of *Quercus robur* (oak forest).

In each habitat, two traps were installed under the forest canopy at a distance of 5 m from each other. Traps were hung on tree trunks in a crown 7m to 8m in height. The sampling period ranged from six to 17 days. The studies were conducted from April to October 2019. The air temperature was measured daily during the day and night (maximum and minimum values). During the experiment, 9012 Lepidoptera individuals were captured and examined.

Horizontal and vertical distribution

In these experiments, both the horizontal distribution of Lepidoptera over individual habitats and the vertical distribution within each habitat were studied (Table 1).

Pairs of traps at two heights (below-above) within the same habitat were located side by side (4-5 m from each other). The studies were conducted from April to August 2020. In total, 10 collections (expositions) were carried out. During the experiment, 6266 Lepidoptera individuals were captured and examined.

Horizontal distribution

In these experiments, we studied the horizontal distribution of Lepidoptera over individual habitats. All traps were located at a height of 1.5 m (Table 2).

The studies were conducted from May to August 2020. In total, 12 collections (expositions) were carried out. During the experiment, 8296 Lepidoptera individuals were captured and examined.

Data analyses

When analyzing the results, we used only data on the quantitative parameter (number) of all Lepidoptera specimens in traps during the exposure time. Determination of the Lepidoptera species was difficult due to poor quality of specimens and the inability to determine the collected material. Exposure time is the period between hanging a trap and taking samples for analysis (expressed in days). All data from individual collections were averaged for the entire duration of the experiments (Experiments 2 and 3).

Table 1. Brief description of the habitat

Name of the habitat	Description of the habitat	Height of the trap location, m
River sandbanks	Open habitat, 5 m from the edge of the Moksha River; herbaceous vegetation is weak	1.5
Willow thickets	Near the floodplain deciduous forest, transitional habitat	1.5
Glade in the forest	Glade in the floodplain deciduous forest, overgrown with nettle	1.5 below
Glade in the forest	Glade in the floodplain deciduous forest, overgrown with nettle	7.5 above
Edge of the forest	Edge of the floodplain deciduous forest, western side, maximum sun illumination	1.5 below
Edge of the forest	Edge of the floodplain deciduous forest, western side, maximum sun illumination	7.5 above
Floodplain meadow	Center of the floodplain meadow, grassy cover is well-developed, herb layer height is up to 1.2 m; herb species diversity is considerable	1.5
Edge of the forest	Edge of the floodplain deciduous forest, eastern side	1.5 below
Edge of the forest	Edge of the floodplain deciduous forest, eastern side	7.5 above
In the depth of the forest	In the depth of the floodplain deciduous forest	1.5 below
In the depth of the forest	In the depth of the floodplain deciduous forest	7.5 above
Edge of the forest	Edge of the floodplain deciduous forest, north side, no direct sunlight	1.5 below
Edge of the forest	Edge of the floodplain deciduous forest, north side, no direct sunlight	7.5 above

Table 2. Brief description of the habitat

Name of the habitat	Description of the habitat
Open habitat	Dry meadow; herbaceous layer is represented by various cereals
The edge of a mixed forest	A young forest appeared as a result of self-seeding in a meadow
Open habitat	Dry meadow; herbaceous layer is represented by various cereals and perennial herbs
Open habitat	Moistened meadow, in a hollow which has water in spring; herbaceous layer is represented by various perennial herbs
The edge of a young pine forest	The edge of a young pine forest formed as a result of self-seeding in a meadow
In the depth of a medium-aged birch forest	The herbaceous layer is poorly expressed, high shading occurs due to the high crown density

RESULTS AND DISCUSSION

Experiments demonstrated that the highest number of Lepidoptera (more than twice) was found in oak forests. The number of specimens differed little from other habitats. Floodplain deciduous forests are very abundant in the species diversity of plants in both herbaceous and understory layers. Apparently, this is the reason for the high number of Lepidoptera there. Gilbert and Singer (1975) and Shapiro (1975) suggested that the relationships of lepidopterans with host plants and climate may explain much of the distribution patterns of the insects. It is also known that there is a direct relationship between the abundance of Lepidoptera and the species diversity of plants (Root et al. 2017).

Similar to majority of other insects, the seasonal cycles of lepidopterans are strictly related to seasonal changes in temperature, day duration, humidity, and other factors. Abundance is influenced by climatic factors that determine the conditions of reproduction and survival (Owen 1971). Seasonality more often depends on the change of rainy and dry seasons in the tropics (Owen et al. 1972; Ribeiro et al. 2010; Grøtan et al. 2012). Photoperiod and temperature indicate the main impact on seasonal phenomena in temperate forests (Roy and Sparks 2000; Altermatt 2012; Zografou et al. 2014; Brooks et al. 2017; Ruchin et al. 2018; Colom et al. 2021).

The seasonal dynamics of Lepidoptera abundance were expressed quite well and it was quite natural (Figure 2). The abundance dynamics were similar in all habitats. In late April, the number of Lepidoptera specimens was very low. Then there was a gradual increase in this parameter. During the season, there were three peaks in the number of lepidopterans. A small first peak in numbers was recorded in the second half of May. Apparently, it was associated with the appearance of imago of the first spring species from various families.

The most considerable peak of Lepidoptera abundance was found in the first half of July. It was clearly associated with the flight and activity of imago in late spring, and summer species after the May high temperatures, which contributed to the accelerated development of larvae. This peak was preceded by a decline in the Lepidoptera number in late June - early July, which is associated with certain diapauses before the appearance of adult insects. The second peak was recorded in early October. In our opinion, this peak was not associated with the Lepidoptera reproduction, but with the activity of these insects. This is indicated by the correlation (ratio of decreases and increases in number) of the trends of the temperature dynamics in September and October and trends of the number of Lepidoptera. The October peaks (most likely all autumn peaks) of increase in air temperatures contribute to the increase in the activity of Lepidoptera in all habitats.

Figure 3 shows the results of experiments on the spatial distribution of Lepidoptera in individual habitats and within each habitat.

In open areas (meadows, river sandbanks), the number of Lepidoptera was low. In the forest depth (habitats 10 and 11), the number of specimens was less than at the nearest edge of the forest (habitats 8 and 9). In low-level traps (h=1.5) (habitats 8 and 10), the number of Lepidoptera was almost the same (26.3 and 26.6 specimens/day, respectively). This means that the activity of Lepidoptera species differs little at low heights.

The highest values of Lepidoptera abundance were obtained in the fringe habitats (Figure 3). In total, all three habitats showed high and slightly different results on the Lepidoptera abundance (Figure 4).

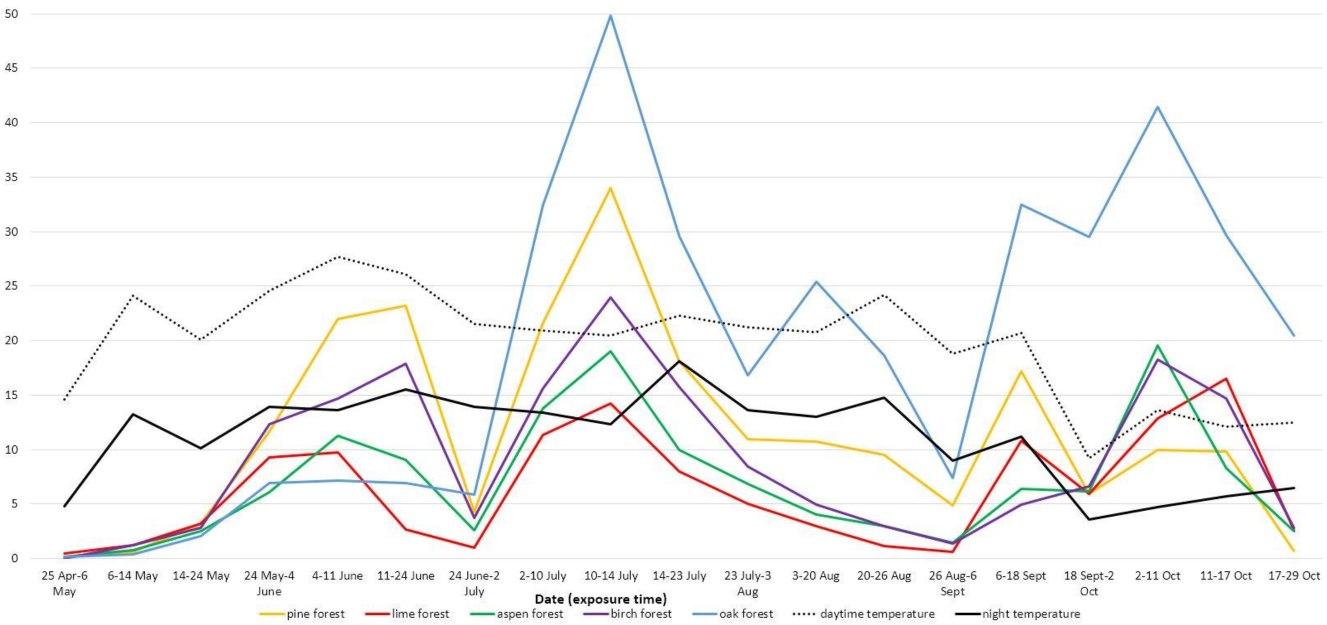

Figure 2. Seasonal abundance of Lepidoptera specimens collected in various habitats from April to October. The graph shows the dynamics of day and night temperatures. Y-axis indicates a numerical expression (number in specimen per day, temperature in ºC)

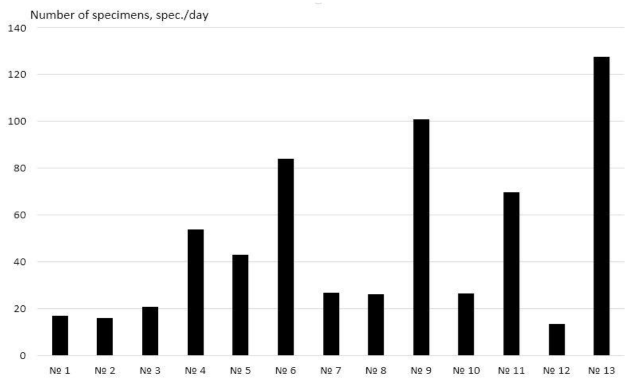

Figure 3. The average number of Lepidoptera (in specimen/day) in all habitats in experiment No. 2

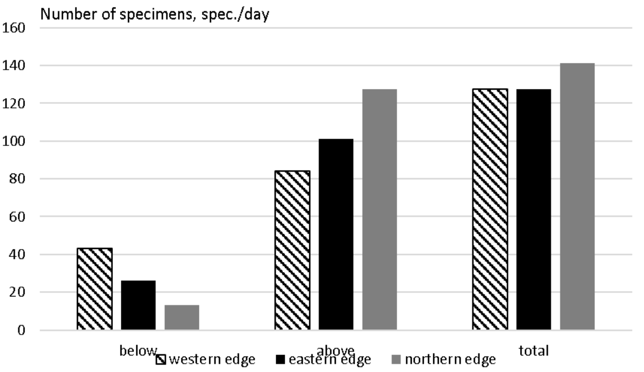

Figure 4. The number of Lepidoptera (in specimens/day) in three habitats on the forest edges. There are data about different heights and total values

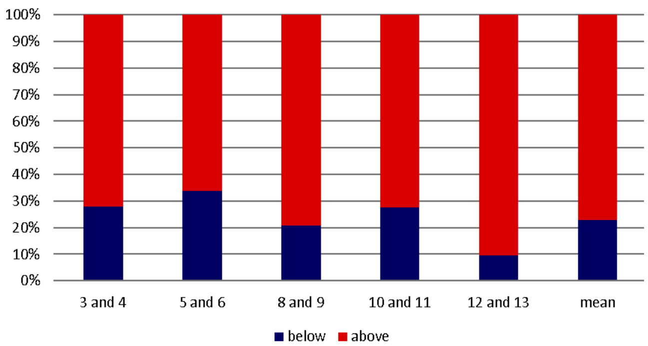

Figure 5. The ratio of the number of Lepidoptera individuals in beer traps located 1.5 m from the ground (below) and in the forest canopy at a height of 7-8 m (above)

However, we noted certain differences in the number of lepidopterans caught at different heights. Thus, it was observed that at a height of 1.5 m, the number of Lepidoptera on the western edge significantly exceeded the number of Lepidoptera at a similar height in two other habitats. On the contrary, at a height of 7.5 m, the number of Lepidoptera on the northern edge was higher than in edges of other expositions.

We assume that in this case, this ratio was influenced by microclimatic conditions, such as illumination, humidity, wind, etc. Especially the first two factors could have an impact on this ratio. Lepidoptera is heliothermic organisms, their flight depends on sunlight intensity (Shapiro 1975). Therefore, open sunny edges are the most preferred for butterflies (Kuussaari et al. 2007). In floodplain meadows in the summer months, there is a frequent drop of dew on the herbaceous layer. Usually, the dew disappears after the sun rises and the surface layer of air warms up. However, at the northern edge, in contrast to the western and eastern edges, the surface layer of air warms up more slowly. In such conditions, in this habitat near the herbaceous cover, the temperature is lower than in similar conditions on other edges. At the same time, temperature differences are less pronounced in the tree crowns. It is possible that it is precise because of such microclimatic conditions that the ratio of Lepidoptera abundance changes towards an increase in the number of individuals in the upper traps.

Figure 5 shows data on the ratio of Lepidoptera abundance at two heights in various locations. In all the habitats, this ratio was shifted towards an increase in the number of Lepidoptera at a height of 7.5 m. In the forest depths, in a clearing in the forest, and in the eastern edge, the ratio of Lepidoptera was twice higher in traps at two heights. However, on the western and northern edges, this ratio changed in the direction of an increase in the number in the upper traps (Figure 4).

The study of the vertical Lepidoptera distribution in temperate deciduous forests demonstrated that there are insect communities unevenly distributed vertically. These patterns are determined by multiple factors acting simultaneously (Ulyshen 2011). Many studies demonstrated that there are also certain patterns in the vertical Lepidoptera distribution (DeVries et al. 1997; Walla et al. 2004; Santos et al. 2017).

At low height, the number of Lepidoptera in various habitats did not vary as much as at higher heights (Figure 6). As we pointed out above, especially in this case, the western edge was distinguished, where the highest number of individuals was observed. On the northern edge, the number of Lepidoptera was lower at low heights than on the river sandbanks, where the herbaceous layer and plant species diversity serving for feeding Lepidoptera are much lower. Apparently, the microclimatic conditions described above are crucial in the Lepidoptera activity and the attraction of this group to bait.

A separate experiment on the horizontal Lepidoptera distribution in individual habitats showed that forest edges adjacent to meadow habitats play a crucial role in the number of Lepidoptera specimens (Figure 7).

At the edge of the young mixed forest, the number of Lepidoptera individuals exceeded the one in the meadow habitat, located 30 m away, by almost three times. The number of Lepidoptera was 2.5 times higher at the edge of a young pine forest than in a nearby meadow habitat (No. 4). At the same time, the differences between meadow habitats with similar conditions (No. 1 and No. 3) were minimal. However, in a more humid meadow habitat, the number of Lepidoptera differed from them.

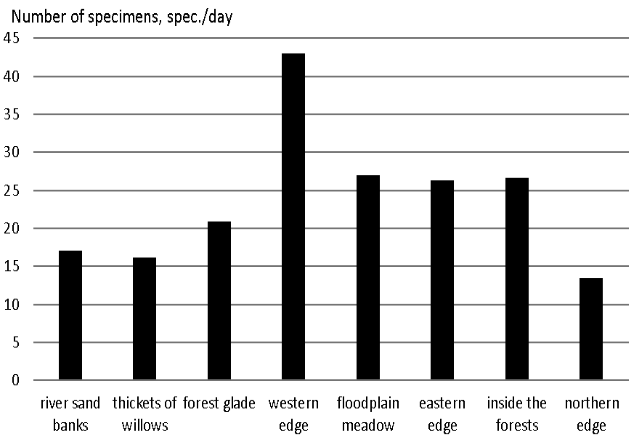

Figure 6. The average number of Lepidoptera (specimens/day) in all habitats at a height of 1.5 m

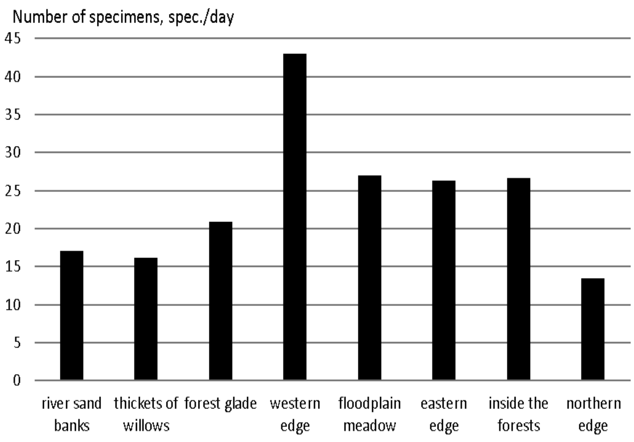

Figure 7. The average number of Lepidoptera (specimens/day) in all habitats in experiment No. 3

Despite certain differences in the population ratio at various heights (Figure 5), forest edges are a hotspot of Lepidoptera abundance and biodiversity in forest habitats (Figures 3 and 7). This is confirmed by other researchers. For example, Lepidoptera species abundance was highest in semi-natural meadows and forest edges (Kuussaari et al. 2007). In the eucalyptus forest and at its edge, the diversity of butterflies was higher than in the adjacent habitats (Bragança et al. 1998). In natural parks of Brazil, similar regularities were found expressed in the increase in the Lepidoptera species richness on the forest edges (Melo et al. 2019).

In conclusion, the largest number of Lepidoptera was found in oak forests in contrast to other four forest habitats. In all habitats, population dynamics were similar, being characterized by the same rates of decrease and increase. In late April, the number of lepidopterans was low. Then there was a gradual increase in the number of traps. During the season, there were three peaks in the number of lepidopterans. A small first peak was recorded in the second half of May, and the maximum peak occurred in the first half of July. This peak was preceded by a decrease in numbers in late June - early July, associated with certain diapauses before the appearance of adult butterflies. The second peak was recorded in early October. Autumn population peaks depend on temperature, while spring and summer peaks are associated with the flight of adults and an increase in the number of butterflies in habitats.

In open habitats, the number of Lepidoptera was usually lower. The highest values of Lepidoptera abundance were obtained in forest edge habitats. Thus, forest edges are a hotspot of abundance and biodiversity in forest habitats. The ratio of the number of butterflies in all habitats was shifted towards an increase at a height of 7.5 m. At low heights, the number of Lepidoptera did not vary as much as at higher heights.

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