Some aspects of vertical distribution of Aculeata (Hymenoptera, Insecta) in glades within forest ecosystems (temperate forests as an example)

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Abstract. The vertical distribution and seasonal abundance of Aculeata in glades in temperate forests of central European Russia was investigated. It was shown that the total number increased at a height of 6 and 8 m and decreased at a height of 2 m. At the same time, the species diversity of this group did not differ at different heights. Beer traps were dominated by social wasps from the family Vespidae, dominated by *Vespa crabro* and *Vespula vulgaris*. The subdominants were *Dolichovespula media* and *Polistes nimpha*. The maximum abundance of *Vespa crabro* was obtained at a height of 6 m, and *Vespula vulgaris* at a height of 8 m. *Polistes nympha* predominated in abundance at a height of 2 and 4 m, and the abundance of *Dolichovespula media* was higher at a height of 8 and 10 m. The seasonal rhythm of abundance included a minimum in June and reached a maximum in July and August. It did not differ at different heights.

1 Introduction

The biological diversity of temperate forest ecosystems is largely dependent on the communities of the ground, herbaceous, and shrub layers. However, the richness and general diversity of these layers are influenced by the structure of communities of the first (tree) layer, composition of tree layers, transparency of crowns, and other factors [1–5]. Upper layers of forest ecosystems modify understory habitat, microclimate, or soil properties [6–8]. Accordingly, in temperate forest ecosystems with well-defined layers, vertical stratification of communities of both invertebrate and vertebrate animals is observed [9–11].

In addition to vertical heterogeneity, any forest ecosystems differ in their horizontal structure. In forest massifs there are always open areas, which have many differences, e.g. in terms of size, location within forests, herbaceous cover, insolation and others. Such glades, meadows, roads are peculiar animal habitats that are characteristic of open ecosystems. Glades in forest ecosystems are often completely surrounded by tree stands. In

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such glades, woody plants closely adjoin the open space and canopy biotopes of different forms are formed [12–14]. Natural edges exist as transitions in growing conditions on the borders of two ecosystems (e.g., forest-meadow ecotones). Anthropogenic edges often exist as abrupt transitions in areas that were once completely forested (e.g., agricultural fields, roads, and building developments) [15–18]. Due to the much denser, more diverse and well-developed grass stand, many species of insect pollinators are found in glades. Among such pollinator groups, various species from Hymenoptera are well known. These are species that prefer open spaces, but are located in forest ecosystems [19–21].

The aim of our work was to study the vertical distribution of Hymenoptera in large glades located in temperate forests of European Russia.

2 Materials and methods

The research was conducted in 2021 and 2022 in the center of the European part of Russia (Republic of Mordovia, Mordovia State Nature Reserve). The Mordovia State Nature Reserve covers an area of 321.62 km^2. This large forest ecosystem has been protected by the state since 1936. This is a zone of coniferous-deciduous forests on the border with the forest-steppe. In general, the vegetation cover of the Mordovia State Nature Reserve has a taiga character with a certain inclination towards the nemoral forest complex. The participation of forest-steppe elements is typical for this territory. In the forest ecosystem, there are quite a lot of glades of different configurations and areas. Usually such plots are completely surrounded by forest [22].

A special installation was constructed for the experiments. It was a hollow tube with a height of 10 m from the soil surface. Every 2 m there were transverse crossbars on this tube. On the crossbars there were traps for collecting insects. There were no obstacles to the movement of species between hanging traps (the installation was described in more detail earlier, [23]). The installation was located in a glade with an area of 0.93 ha, which is bordered by a lake on the south side.

Hymenoptera were collected from May to October using traps of our own design (a detailed description of the trap was made earlier: [24]). Beer was used as bait ("beer traps"). Sugar was added to it for fermentation. Baited traps are well used for catching social insects [25,26]. Collected specimens were placed in plastic bags containing 70% alcohol. The specimens were then identified in the laboratory. A total of 4603 specimens were studied.

3 Results

During two years of the research, a total of 17 species of Aculeata were registered in the studied glade (Table1). However, species from the Vespidae family prevailed in the traps. They accounted for 99.2% of the total number of individuals.

Table 1. Distribution of Aculeata abundance in a glade in a forest ecosystem at different heights (based on 2021 and 2022 data).

Family, species	2 m	4 m	6 m	8 m	10 m	**Total**
Apidae						
Apis mellifera Linnaeus, 1758	2	1	1		1	5
Crabronidae						
Ectemnius cephalotes (Olivier, 1792)	4	2	2	4	1	13
Mellinus arvensis (Linnaeus, 1758)				1		1
Psenulus pallipes (van Lith,			1	1		2

1973)						
Chrysididae						
Chrysis ignita (Linnaeus, 1758)	1		2	1	4	8
Pompilidae						
Priocnemis perturbator (Harris, 1780)	1	1	1		1	4
Eumenidae						
Ancistrocerus trifasciatus (Müller, 1776)		2			1	3
Symmorphus murarius (Linnaeus, 1758)		1				1
Vespidae						
Discoelius zonalis (Panzer, 1801)	1		1		1	3
Dolichovespula media (Retzius, 1783)	34	38	35	40	58	205
Dolichovespula saxonica (Fabricius, 1793)	2	1	4	8	3	18
Polistes dominula (Christ, 1791)	1	2	3	1	1	8
Polistes nimpha (Christ, 1791)	33	48	18	28	28	155
Vespa crabro Linnaeus, 1758	438	409	478	400	332	2057
Vespula germanica (Fabricius, 1793)	8	12	12	8	13	53
Vespula rufa (Linnaeus, 1758)	2		3	2	4	11
Vespula vulgaris (Linnaeus, 1758)	270	307	484	514	481	2056
Number of species	13	12	14	12	14	17
Total	797	824	1045	1008	929	4603

This information confirms the possibility of using beer traps for fishing Vespidae [25,26]. From this family, the traps were dominated by *Vespa crabro* and *Vespula vulgaris*. The maximum abundance of the first species was obtained at heights between 2 and 8 m, whereas at 10 m the abundance of the species was low. The maximum abundance of *Vespa crabro* was obtained at a height of 6 m. The abundance of *Vespula vulgaris* was maximum in traps at a height of 8 m, and the abundance was minimal at a height of 2 m. Note that some other species also had some dependence of abundance on height. Thus, *Polistes nympha* predominated in abundance at a height of 2 and 4 m, and the abundance of *Dolichovespula media* was higher at a height of 8 and 10 m. Other Aculeata species did not have any significant abundance during the study period.

The total number of all species was greatest at a height of 6 and 8 m and lowest at a height of 2 m. In terms of the number of species, the differences between traps at different heights were not significant.

The seasonal dynamics of Aculeata were approximately similar in different years of the research (Figure 1). In May, after the species began to be active, the abundance was small. A decrease in the abundance was observed in June. However, there was a sharp increase in the abundance of individuals in July, which peaked in August and then declined in September and October.

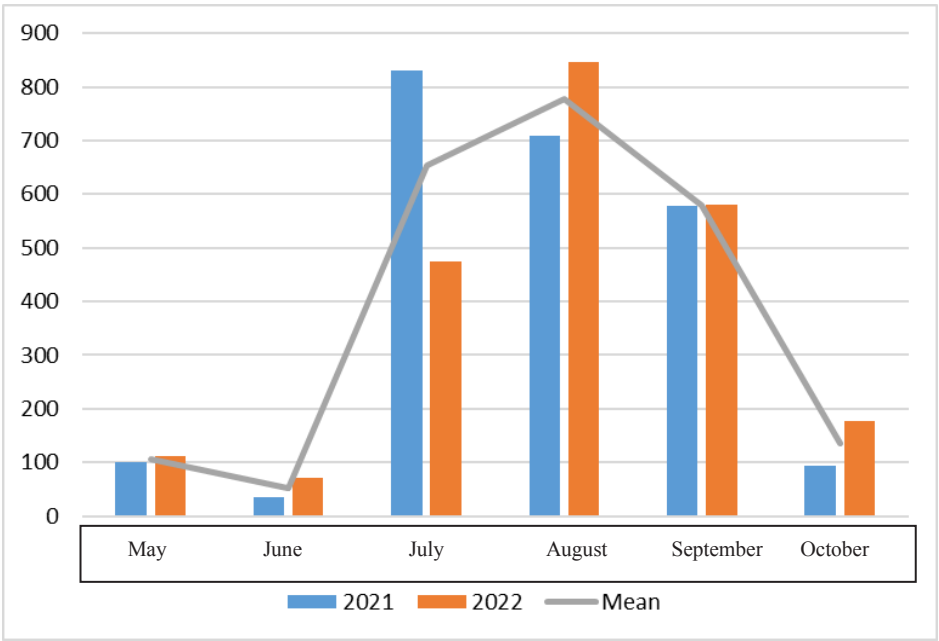

Fig. 1. The seasonal dynamics of Aculeata abundance in 2021 and 2022 in a forest glade (Center of European Russia).

At the same time, the seasonal dynamics of abundance at different heights coincided with the general pattern described earlier (Figure 2).

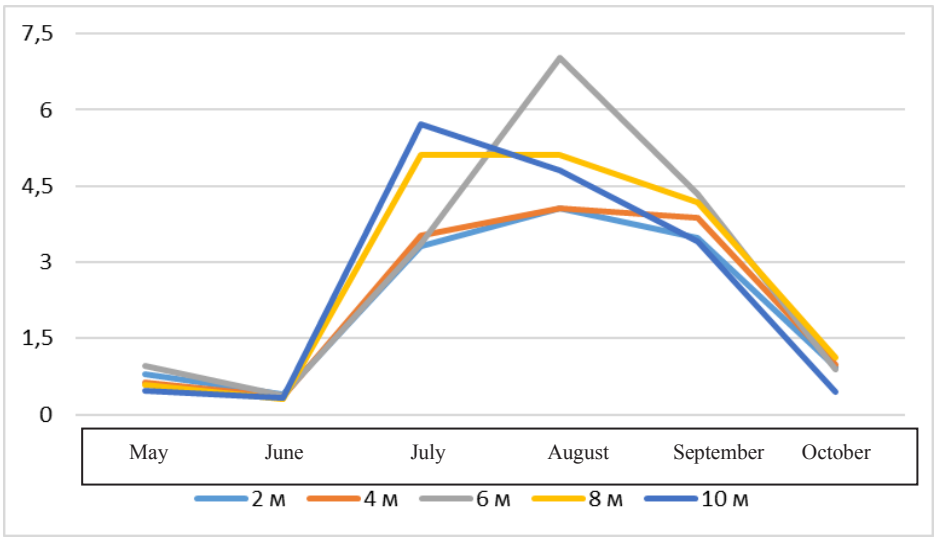

Fig. 2. The seasonal dynamics of Aculeata abundance at different heights in a forest glade (Center of European Russia): average data for two years of the research.

4 Discussion

In our research, we studied the vertical stratification of Aculeata in an open biotope, i.e. in a forest glade. It was found that the abundance of Aculeata was higher when traps were

installed at a height of 6 and 8 m. At the same time, the species diversity of this group did not differ at different heights. In general, the vertical stratification of animal communities was observed in several arthropod taxa [27–29]. Previously, the highest species diversity and abundance of Coleoptera were obtained at a height of 2 m, the lowest species diversity and abundance were obtained at a height of 10 m [23]. However, different results were obtained for Hymenoptera. For example, there was no evidence of Euglossini stratification in terms of diversity, but abundance was higher in the understory. Moreover, the higher abundance of Euglossini in the understory decreases with increasing both latitude and height above sea level [30]. Torretta and Marrero [31] found no significant difference in the vertical distribution of Hymenoptera in tropical forests. Giovanni et al. [32] showed that the bulk of the Sphecidae community lives in the understory and in the forest canopy, there are species that prey on aphids, thrips and psocids.

In our research, several species had the highest abundance in traps, for which representative samples were taken. One of the most common types is *Vespa crabro*. It usually builds nests in hollow trees, attics and other shelters [33]. We also observed nests in rodent burrows. The nest shell is fragile, as the material is wood fibers from rotten stumps and trunks. In hollows, the outer shell may be absent. Prey is a variety of large insects. Bees, grasshoppers, bumblebees, and horseflies were observed as food items. The family develops from May to October. *Vespa crabro* flies well into beer traps. It often inhabits moist areas. Our results are consistent with other data indicating that the species has the highest abundance in lowland floodplain forests and oak woodlands [34,35].

Another dominant species in beer traps is *Vespula vulgaris*. Nests are covered with a wavy outer shell, hidden mainly in underground cavities (often in abandoned rodent burrows) or in wall cavities and under buildings. Prey is small insects (various dipterans). The family development cycle continues from May to October [33]. It is the most widespread and numerous species of social wasps in the center of European Russia. According to some data, this species absolutely dominates in open habitats and is more often found in meadows and glades than in forest ecosystems [34,36].

Dolichovespula media was the third most abundant species in the traps. This species is usually categorized as a forest species that prefers relatively moist areas. In addition, it can be found in open spaces, but such areas must contain shrubs or small trees [37,38]. Nests of this species have a dense gray outer shell, openly hanging in the middle or upper tier on branches of trees and shrubs or under eaves of buildings. Prey for the species is mainly various dipterans. The family development cycle is short – from late May to August.

Polistes nimpha was trapped in small numbers. Previously it was believed that the species could be caught in greater numbers in beer traps that are set close to the ground, as this species prefers to fly close to the ground at the height of herbaceous vegetation [34]. We confirm this hypothesis. In beer traps, which are located at a height of 7-8 m, the abundance of the species is low [39]. However, in open spaces (burned areas, meadows, forest edges) in traps located at a height of 1.5 m, the species is found regularly and in high numbers. This research also proved that the species abundance is higher in traps located at a height of 2 and 4 m than in higher traps. *Polistes nimpha* builds nests in the form of a horizontal or inclined cell open from below on a single pillar on plant stems or, in shelters, with several pillars [40]. Its prey is small caterpillars (mainly Geometridae and Tortricidae).

Vespidae, which predominated in beer traps, feed on water, carbohydrates (sugars) and animal food [41]. To do this, they use all the opportunities available in their habitat. Open glades usually have well-developed herbaceous vegetation from which nectar can be collected and on which Vespidae prey items are found. The obtained seasonal dynamics are characteristic for many species of Vespidae in temperate forests. Such cycles of abundance in social wasps are associated with a long cycle of nest development. Overwintered female

social wasps become active after hibernation in April and May. They begin to build nests and lay eggs. The decrease in numbers in June is associated with the death of females, and the increase in numbers in July is associated with the appearance of a large number of working individuals, which then feed a larger number of new larvae and the appearance of new working individuals [42,43].

5 Conclusion

The research on glades in temperate forests of the center of European Russia showed that the abundance of Aculeata increased at a height of 6 and 8 m and decreased at a height of 2 m. At the same time, the species diversity of this group did not differ at different heights. The beer traps were dominated by social wasps from the family Vespidae, with *Vespa crabro* and *Vespula vulgaris* dominant. The subdominants were *Dolichovespula media* and *Polistes nympha*. The maximum abundance of *Vespa crabro* was obtained at a height of 6 m, and *Vespula vulgaris* at a height of 8 m. *Polistes nympha* predominated in abundance at a height of 2 and 4 m, and the abundance of *Dolichovespula media* was higher at a height of 8 and 10 m. The seasonal rhythm of abundance included a minimum in June and reached a maximum in July and August. At different heights, it did not distinguish itself.

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