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Research Article

Edge effects on Diptera distribution in deciduous forests of the centre of European Russia

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Abstract

Studies were conducted in the temperate forests of the European part of Russia (territory of the Republic of Mordovia). Beer traps with bait made of beer and sugar were used for the studies. Three plots were selected for the study, which differed in the composition of plants at the edges, adjacent open ecosystems and types of forest ecosystems. The forest was adjacent to this open ecosystem and there was no transition zone of shrubs. Eight traps were used in each plot (1,2 - edge-below, 3,4 - edge-above, 5,6 - forest interior-below, 7,8 - forest interior-above). They were located 1.5 m (further named as "below" traps) and 7.5 m (further named as "above" traps) from the ground level. During the experiments, 52306 specimens from 28 families of Diptera were captured. In terms of total abundance, representatives of 25 families were present in the lower traps and species from 27 families were present in the upper traps. The general pattern was the highest abundance of Diptera at the edges in all plots. Nine families (Tipulidae, Anisopodidae, Lonchaeidae, Milichiidae, Drosophilidae, Anthomyiidae, Fanniidae, Muscidae, Calliphoridae) accounted for 93.3% of all Diptera abundance in all plots. The families Tipulidae, and Drosophilidae were the most abundant in lower traps within forest ecosystems. The families Lonchaeidae, Milichiidae, Anthomyiidae, Fanniidae, and Muscidae were most abundant in upper traps at the edges of forests. The families Anisopodidae, Calliphoridae were the most abundant in the lower down edges.

Keywords: insects, below, above, forest interior.

Introduction

Invertebrates, as the most abundant group, provide important services to different ecosystems. With their diverse roles, they have become indispensable components of all biomes (Ssymank et al., 2008; Scherber et al., 2014; Dvořák et al., 2023; Dedyukhin 2023; López-Rojas et al., 2023). Diptera is one of the three largest and most diverse groups of insects in the world's fauna. Ten years ago, it was estimated that there were more than 160,000 species (Zhang 2013). They are major contributors to the maintenance of animal and plant biodiversity, playing a variety of roles in ecosystems. For example, pests can have significant impacts on agriculture, animal and human health, and forestry. At the same time, Diptera plays valuable roles as pollinators of flowering plants, parasitoids and predators of other insects, food for predators, scavengers, bioindicators of water quality and tools for scientific research (Rotheray et al., 2001; Ssymank et al., 2008; Courtney et al., 2017).

Biodiversity experiments have shown that plant diversity has a significant positive effect on insect diversity and abundance. However, such relationships have rarely been studied in undisturbed and more complex ecosystems such as forests (Scherber et al., 2014). Edges are ecotones because they are located at the boundaries of two ecosystems: open landscapes (meadows, glades, etc.) and closed ecosystems (forests). They can be formed either by natural processes or by anthropogenic activities (Ewers and Didham, 2006). At the same time, the second variant of the occurrence of forest edges is more and more common, and it is associated with the fragmentation of landscapes due to human activities (Peltonen et al., 1997; Ouin et al., 2006; Magura, Lövei, 2020a; Ruchin et al., 2021).

Edge effects are observed due to changes in abiotic factors in these locations. Temperature, humidity, wind, and location in relation to the sun have a significant influence on the distribution of insect species, families, and orders (Murcia 1995; Didham and Lawton 1999; Ruchin 2021). For example, Phytomyza ilicis prevalence was higher while survival was lower at the forest edge (McGeoch and Gaston 2000). Culicidae abundance was higher at the forest edge and within the forest than in open habitats (Costa et al., 2023). The highest numbers of Syrphidae species were found on forest edges and fields covered with wild grasses and shrubs, while some other Syrphidae species were predominant on agricultural crops (Koval et al., 2018). The results of other studies have revealed a certain gradient in the distribution of drosophilid species abundance along the transect between edges and interior areas in a forest plot (Penariol and Madi-Ravazzi 2013). However, edge effects are not always observed and not for all Diptera families and species in ecosystems. Edge effects were observed in Calliphoridae inhabiting ecosystems in a biological reserve in the city of Nova Iguaçu, State of Rio de Janeiro (Gadelha et al., 2015). No significant differences in the number of individuals or species of Psychodidae were observed along the gradient from the border to the interior of the forest (Azevedo et al., 2011).

The study aims to investigate the forest edges effects on the abundance and species diversity of Diptera. The objectives of the study are: 1) to determine the number of individuals of

Diptera families at forest edges and inside the forest; 2) to determine the number of individuals of Diptera families at two heights above the ground.

Materials and methods

The research was conducted in the centre of European Russia (the western part of the Republic of Mordovia) (Figure 1). The western part of the region is located in the Oka-Don Lowland. In total 3 plots were studied. Each sampling plot represented an open ecosystem (a large meadow in the centre of a forest ecosystem, a meadow, an agroecosystem) and a deciduous forest nearby. The forest ecosystem was adjacent to the open ecosystem and did not form a transitional biotope in the form of shrubs or undergrowth forests. A forest edge was formed at the boundary between the open space and the forest ecosystem. Traps were placed on this forest edge. Two heights for setting traps above the ground were determined: 1.5 m (named as “below” traps) and 7.5 m (named as “above” traps). The traps were hung from tree branches. In addition, 300-350 m in the forest interior, traps were also placed similarly. All experiments were performed simultaneously in two repetitions (i.e. 2 traps at each height). In addition, nine series of experiments were performed in plot1 and three series of experiments were performed in plot2 and plot3. Thus, each plot had 8 traps (1,2 – edge–below, 3,4 – edge–above, 5,6 – forest interior–below, 7,8 – forest interior–above).

a

b

c

Figure 1. Research sites (photos of biotopes): 1 – plot1; 2 – plot2; 3 – plot3.

Plot 1 was located in a large forest ecosystem. A clearing with an area of about 1 hectare is located inside this forest. At the forest edge of plot1, the crown layer is formed by *Betula pendula*. Shrub layer is sparse, and presented by single individuals of *Rubus idaeus, Acer platanoides*, and undergrowth of *Ulmus* sp., *Quercus robur*. Ground layer contains *Viscaria vulgaris, Festuca pratensis, Phleum pratense, Rumex acetosella, Galium mollugo, Veronica officinalis, Hypericum perforatum, Trifolium medium, Elytrigia repens, Convolvulus arvense, Achillea millefolium, Ranunculus acris, Geum urbanum, Melampyrum pratense, Clinopodium vulgare, Lathyrus vernus, Leonurus quinquelobatus, Dactylis glomerata*. In the forest interior of plot1, percent cover of the crown layer is 50-60%; it is formed by *Betula pendula*. Shrub layer (percent cover: 40%) includes *Frangula alnus* (10%), *Lonicera xylosteum, Acer platanoides* (10%), *Prunus padus, Rubus idaeus*, and undergrowth of *Ulmus* sp. (30%), *Quercus robur, Pinus sylvestris, Tilia cordata*. Ground layer (percent cover: 70%) contains *Glechoma hederacea* (30%), *Pulmonaria obscura* (10%), *Urtica dioica, Asarum europaeum, Galium mollugo, Moehringia trinervia, Geum urbanum, Stellaria holostea, Milium effusum, Scrophularia nodosa, Festuca gigantea, Veronica officinalis, Melampyrum pratense, Leonurus quinquelobatus, Lathyrus vernus*. A large glade with an area of about 1 hectare is located next to plot 1. Weeds are the main part of its vegetation. The following species have been registered: *Agrostis gigantea, Potentilla argentea, Plantago major, P. media, Elymus repens, Dactylis glomerata, Geranium pratense* and others; form several thicket patches here.

Plot2 is a large forest surrounded on all sides by agroecosystems. At the forest edge of plot2, crown layer (percent cover: 30%) is formed by *Quercus robur*. The second crown layer is represented by *Betula pendula* and *Pinus sylvestris*. Shrub layer is relatively dense (percent cover: 30%) and includes *Sorbus aucuparia* and undergrowth of *Quercus robur* and *Malus domestica*. Ground layer contains *Pimpinella saxifraga, Galium mollugo, Fragaria vesca, Hypericum perforatum, Viola hirta, Filipendula vulgaris, Campanula trachelium, Glechoma hederacea, Poa nemorosa, Agrimonia eupatoria, Galium boreale, Aegopodium podagraria, Geranium sylvestre, Veronica chamaedrys, Dactylis glomerata, Vicia sepium, Geum urbanum, Pyrethrum corymbosum, Solidago virgaurea, Trifolium medium*. At the forest interior of plot2, percent cover of the crown layer is 80%; it is formed by *Quercus robur* and **Betula pendula**. The second crown layer includes *Betula pendula*, *Larix sibirica* (artificial plantations). Shrub layer (percent cover: 50%) includes *Frangula alnus, Sorbus aucuparia, Prunus padus, Sambucus racemosa, Amelanchier spicata, Viburnum opulus*, young *Quercus robur*. Ground layer (percent cover: 80%) is formed by *Aegopodia podagraria, Stellaria holostea, Glechoma hederaceae, Geum urbanum, Lathyrus vernus, Campanula rapunculoides, Pimpinella saxifraga, Betonica officinalis, Galium mollugo, Viola hirta, Agrimonia eupatoria,* *Carex spicata*, *Calamagrostis arundinacea*, *Scrophularia nodosa*. Near the studied oak forest, croplands are located, being represented by winter wheat crops.

Plot3 is the edge of a large forest ecosystem, near which meadow ecosystems are located. At the forest edge of plot3, the crown layer is formed by *Betula pendula* (percent cover: 20-30%). Shrub layer is sparse and includes *Malus domestica, Salix caprea, S. cinerea, Frangula alnus, Sorbus aucuparia*. Ground layer is well developed (percent cover: 80-85%) and includes *Melampyrum nemorosum, Phleum pratense, Leucanthemum vulgare, Trifolium hybridum, Pimpinella saxifraga, Seseli libanotis, Knautia arvensis, Achillea millefolium, Cichorium intybus, Deschampsia cespitosa, Erigeron annuus, Vicia cracca, Lysimachia vulgaris, Veronica chamaedrys, Angelica sylvestris, Anthoxanthum odoratum, Galium mollugo*. At the forest interior of plot3, crown layer (percent cover: 50%) is formed by *Betula pendula*. The transparency of the crowns of the trees of the first tier is high. Shrub layer is sparse (percent cover: 5–10%) and includes *Sorbus aucuparia*, *Frangula alnus*, and undergrowth of *Populus tremula*. Ground layer (percent cover: 70-80%) includes *Rubus saxatilis, Pimpinella saxifraga, Melampyrum nemorosum, Viola canina, Fragaria vesca, Phleum pratense, Plantago lanceolata, Hypericum perforatum, Dryopteris carthusiana, D. expansa, Leucanthemum vulgare, Platanthera bifolia, Agrostis gigantea, Deschampsia cespitosa, Convallaria majalis, Chamaenerion angustifolium*. Near plot3, old abandoned lands are located, where weed vegetation is developed after abandoning of arable lands about 30-35 years ago. Its vegetation is formed by plant communities of *Cychorium intybus, Agrimonia eupatoria, Calamagrostis epigejos, Artemisia campestris, A. vulgaris, Ranunculus polyanthemos, Cirsium arvense, Galeopsis* spp., *Medicago falcata, Euphorbia virgata* and others.

Diptera were collected in the spring-autumn period of 2020-2022. At this time, insect activity is the highest in the temperate zone of Russia. Samples were collected using traps of our own design. Details of the design, installation and baits are described earlier (Ruchin et al., 2020). Collected samples were usually placed in plastic dishes to which 70% alcohol was added. Specimens were sorted, counted and identified in the laboratory. The list of families is given using the publication (Courtney, et al., 2017).

The number of individuals of different Diptera families in the traps during exposure time was used in the analyses. Exposure time is the period between hanging a trap and taking samples for analysis (expressed in days).

Results

During the experiments, 52306 specimens from 28 families of Diptera were captured (Figure 1). In terms of total abundance, nine families (Bibionidae, Tabanidae, Hybotidae, Phoridae, Ulidiidae, Platystomatidae, Pallopteridae, Piophilidae, Scathophagidae) were represented by no more than 100 specimens in all plots. Nine families (Tipulidae, Anisopodidae, Lonchaeidae, Milichiidae, Drosophilidae, Anthomyiidae, Fanniidae, Muscidae, Calliphoridae) were represented by more than 1000 specimens. In total, these nine families accounted for 93.3% of the total number of all Diptera in all plots.

The largest number of Diptera was captured it plot1 (more than 45,000 specimens). Experiments in this forest ecosystem were conducted from June to September (56.2 specimens were captured per trap per day on average). Much lower abundance of Diptera was observed in plot2 and plot3. In plot2 only 15.6 specimens were trapped per day, and in plot3 only 9.4 specimens were captured per trap per day.

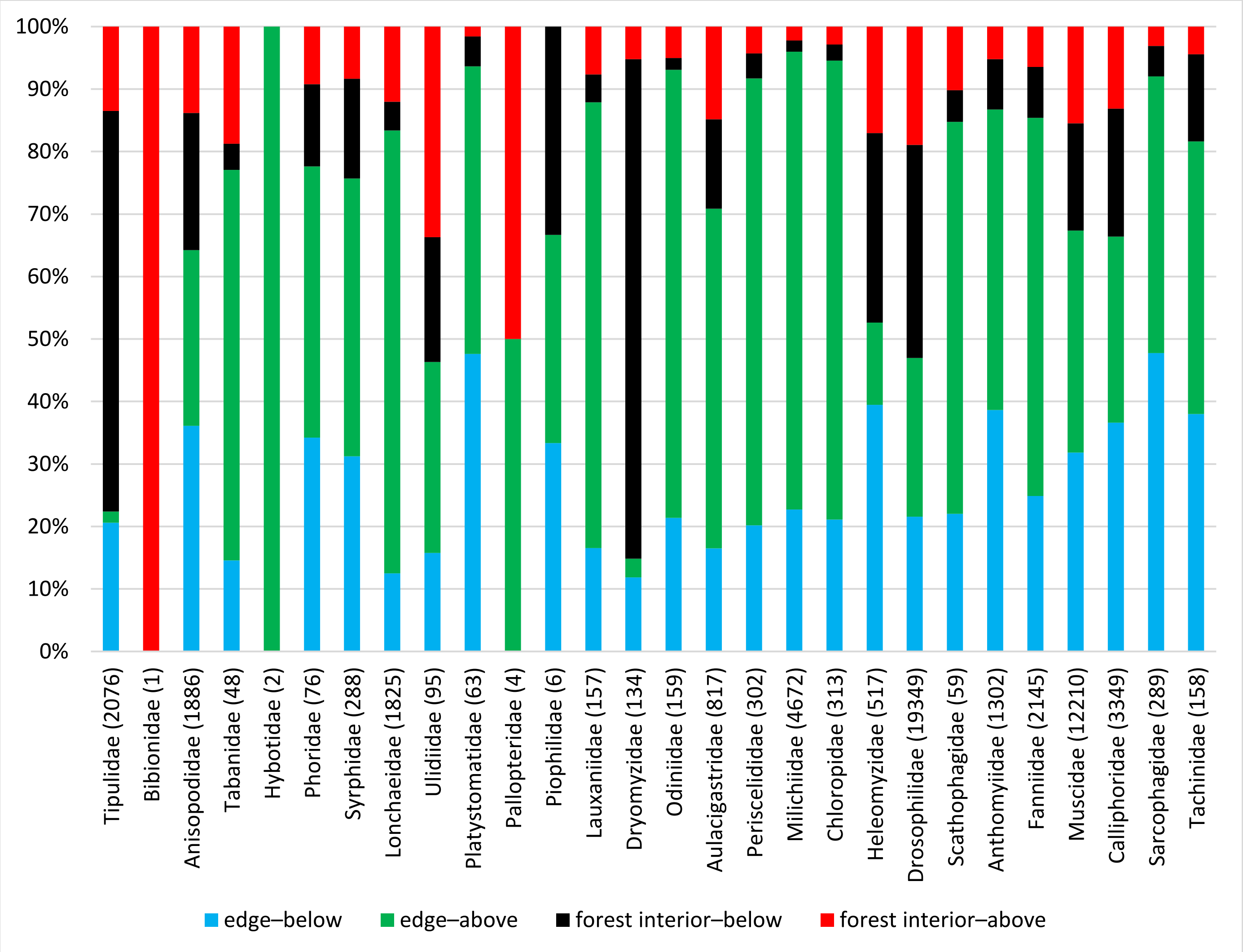

Figure 1. Percentage of abundance (average of three plots) of Diptera families at edges and within forest ecosystems (total number of specimens is indicated in brackets).

There were 26 families common for all plots. Only two plots had in common three families (Lauxaniidae, Piophilidae, Chloropidae in plot1 and plot2). Each plot had one unique family that was not observed in other plots (Dryomyzidae in plot 1, Pallopteridae in plot1, Bibionidae in plot3).

In addition to the clearly visible horizontal distribution along the edge-forest interior, we also observed different abundance of Diptera families by height. The families Tipulidae, Dryomyzidae, and Drosophilidae were most abundant in lower ("below") traps within forest ecosystems. The family Ulidiidae was most abundant in upper ("above") traps, both at the edges and within forested areas. The families Tabanidae, Syrphidae, Lonchaeidae, Lauxaniidae, Odiniidae, Aulacigastridae, Periscelididae, Milichiidae, Chloropidae, Scathophagidae, Anthomyiidae, Fanniidae, Muscidae were the most abundant in upper traps at forest edges. The families Phoridae, Platystomatidae, Sarcophagidae and Tachinidae were most abundant in the upper and lower edges of the forest. The families Anisopodidae, Heleomyzidae, Calliphoridae were the most abundant on the edges below (Figure 1).

In terms of total abundance, representatives of 25 families were present in lower traps at edges, while species of 27 families were present in upper traps. At the same time, within the forest, 28 families were present in lower traps and 26 families in upper traps.

The general pattern was the highest abundance of Diptera at the edges in all plots (Figure 2). The most distinct ratio of abundance at edges and within forest ecosystems towards edges was shown in plot2 (2.16 times more) and plot1 (1.7 times more). In plot3 this ratio was only 1.1 times. There were no differences in the number of families obtained at the edges and within the forest. However, species from Bibionidae were absent at edges, and species from Hybotidae were absent in the forest interior.

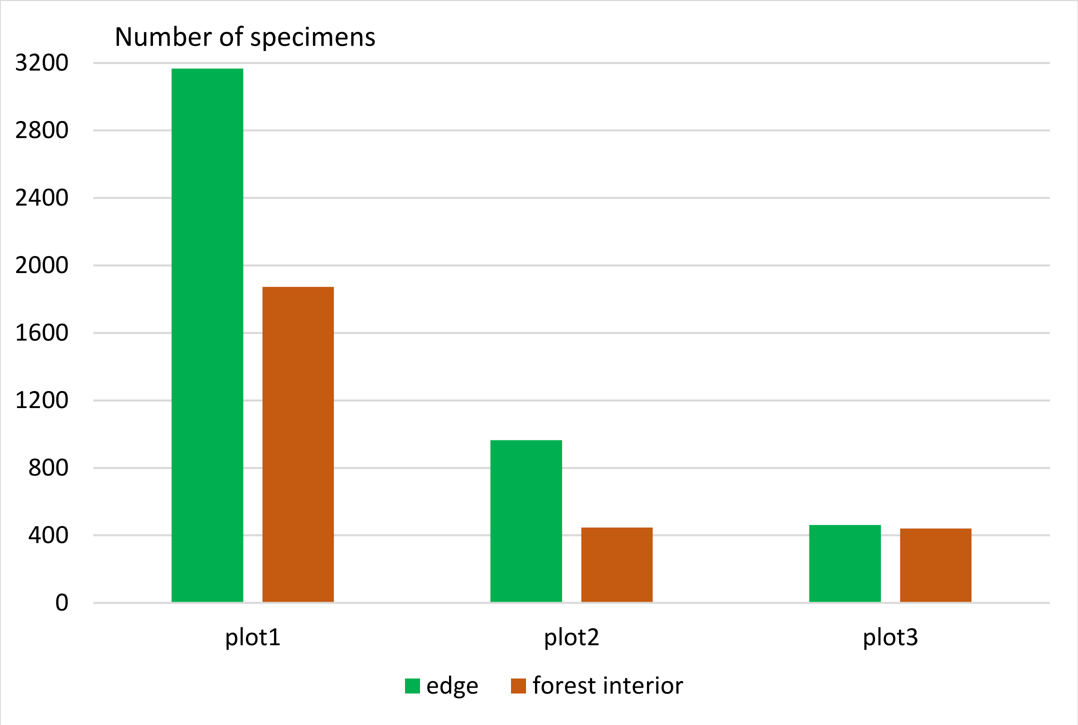

Figure 2. Average abundance of Diptera families at edges and within forest ecosystems during the experiments.

The total abundance of all Diptera in plot2 and plot3 was higher on the lower edges than on the upper edges (Figure 3). Only in plot1 we observed an inverse correlation: the abundance of all Diptera was higher at the top of the forest edge than at the bottom. In the forest interior, the pattern was the same for all plots, with significantly higher abundance in the lower traps.

There were also more Diptera in the lower traps at the edge of the forest than in the lower traps inside the forest. A similar pattern was obtained for the upper ("above") traps.

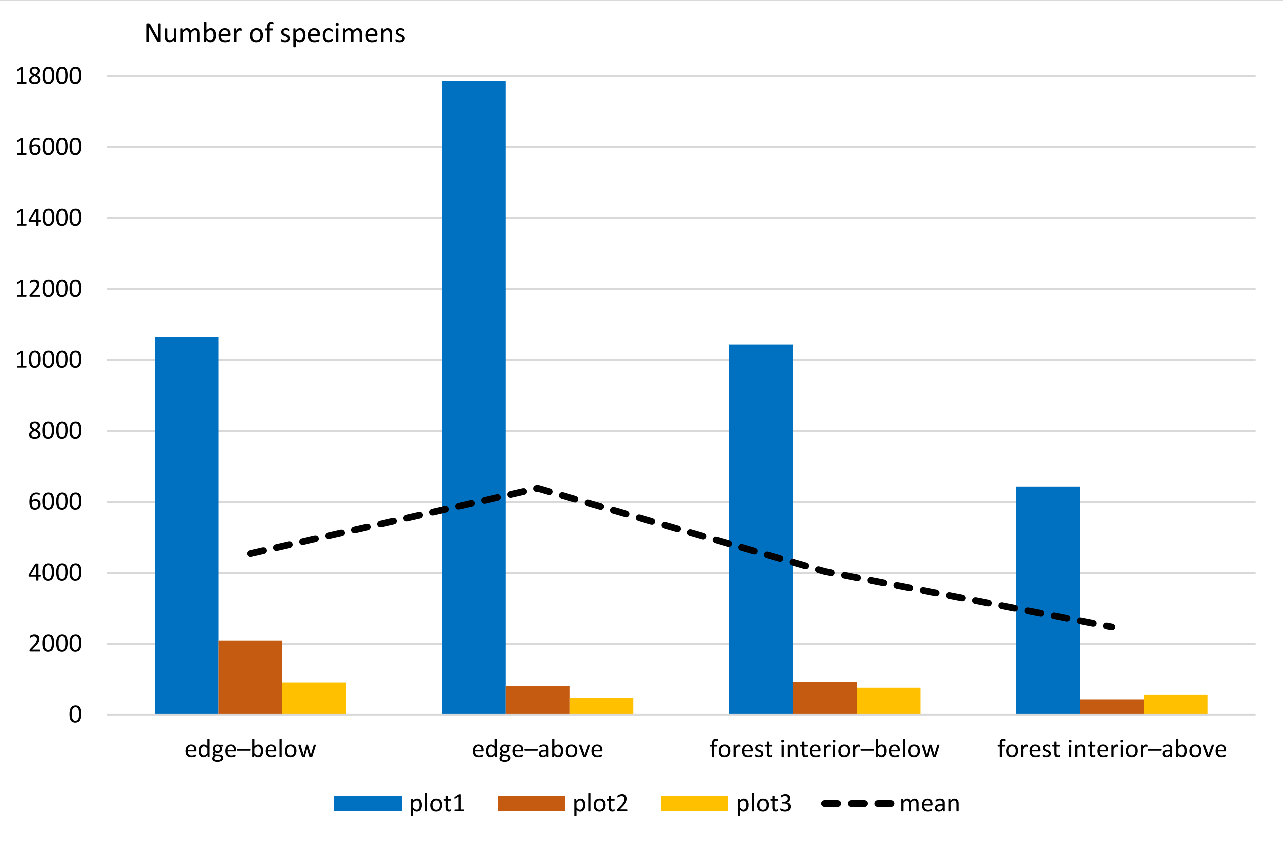

Figure 3. Numbers of Diptera families collected with beer traps at forest edges and forests interior at different heights from the ground level.

Discussion

This is the first study conducted on deciduous forest edges in European Russia that gives an idea of the abundance of Diptera families. Diptera were collected using beer traps. Forest habitats (ecotones) usually represent a fairly sharp transition between two homogeneous biotopes. They are transition zones that can contribute to biodiversity conservation as they are usually species-rich compared to neighbouring habitats (Kark, Van Rensburg, 2006; Bogyó et al., 2016; Uchoa et al., 2023). Our results show that the total abundance of Diptera is higher at edges than in the forest interior. In addition, we found differences in the abundance of families based on the height of trap locations.

It is important to pay attention to the very high abundance of Diptera in forest ecosystems (plot1). The forest ecosystem, in contrast to other ecosystems, is a large forest that extends over an area of more than 100 thousand hectares. The ecosystems of this forest have been protected for more than 80 years and therefore the forest does not experience any anthropogenic influence. This forest ecosystem hosts many rare species (Ruchin, Kurmaeva 2010; Ruchin, Khapugin 2019) and has repeatedly found species new to Europe and Russia (Bolshakov et al., 2021; Dvořák et al., 2022; MacGowan, Ruchin 2022; Esin et al., 2023). In the other two plots, the abundance of Diptera that were caught in traps is much lower. We think that this is due to significant anthropogenic influence on these ecosystems. Forests in these habitats are not protected and are frequently visited by humans. Open ecosystems are disturbed habitats: agro-ecosystems and grasslands that have been formed on the site of former agro-ecosystems. In such open disturbed habitats, Dipetra abundance is usually always lower than in natural open ecosystems (Mudri-Stojnic et al., 2012; Oplanić et al., 2021; Goethe et al., 2021).

At the same time, certain differences in results were obtained in different plots. Plot3 had the most even distribution of Diptera in this ecosystem. More or less even distribution of almost all families was obtained on the forest edge and inside the forest, both below and above. This is probably due to the high transparency of the forest edge for flying diptera. It is known (Dangerfield et al., 2003; Ewers and Didham, 2008) that edge effects penetrate deep into forested areas and depend on the transparency of the stand and shrub layer. Invertebrate community composition and abundance can change gradually over significant distances from the edge into the forest (Dangerfield et al., 2003; Ewers, Didham, 2008). Factors that may contribute to variability in edge effect include edge type, age of edges, major woody vegetation types, structure of adjacent vegetation, seasonality, influx of animals or plants from surrounding areas, catastrophic events, logging, and some weather events (Fletcher et al., 2007; Buras et al., 2020; Ruchin et al., 2021; MacBride-Stewart et al., 2023). Given that the birch forest in plot3 was very transparent to flying insects, it seems to us that this favoured an even distribution of Diptera at the edge and in the forest interior. Therefore, the edge effect was less evident in this plot than in other plots.

We will focus on the discussion of preferences of those families whose total abundance exceeded 100 specimens in all plots during the whole period of experiments (these are 19 families). Tipulidae is one of the families whose total abundance in all plots exceeded 1000 specimens. Larvae of most species of Tipulidae inhabit semi-aquatic, strongly moistened or aquatic habitats. The terrestrial and semiterrestrial larvae live in moist soil, moist wood, often in mosses. Tipulidae larvae are more abundant in soils prone to waterlogging, and low soil moisture is a limiting factor for them. All adult Tipulidae are terrestrial, usually stick to moist habitats, adults fly poorly (de Jong et al., 2007; Wagner et al., 2008; Palatov et al., 2016). According to Allgood et al. (2009), Tipulidae constituted a higher proportion of the community in edges than in closed crowns or thinned stands. However, different results were obtained in our experiments. We think that due to poor flight ability and comparatively higher humidity, members of this family were found in the highest abundance at lower heights within forested areas.

Anisopodidae is one of the families, with total numbers exceeding 1000 specimens in all plots. Their highest abundance was recorded at the edges of the forest in the lower traps. Numbers were also higher inside the forest and also in lower traps. According to Maguire et al. (2014), Anisopodidae were captured in the highest numbers in the understorey, while they were not present at all in the canopy. The larvae of this family are saprophagous and inhabit a wide variety of decaying plant materials (Krivosheina, Menzel 1998; Manko et al., 2018; Ruchin, Esin, 2021). Apparently, a wide range of opportunities for larval development and high flight activity of Anisopodidae allow species of this family to inhabit a variety of habitats.

Representatives of the family Syrphidae are active species with good flight performance. Larvae of some species inhabit the nests of social Vespidae (Ball and Morris 2004). Male Syrphidae are well known for their territorial behaviour as they hover at some altitude in open meadows, grasslands, pastures, agro-ecosystems. In doing so, they defend their territories and their behaviour is closely related to feeding issues (Molthan 1990; Ball, Morris 2004). Apparently, this is why adults of Syrphidae were most abundant in the upper traps at the edges of the forests.

Lonchaeidae is one of the families, with total numbers exceeding 1000 specimens in all plots. Larvae of Lonchaeidae are saprophagous and feed on decaying plant remains. They live under the bark of dead or dying trees, in decomposing wood (Szwejda, 2003; MacGowan, 2015). The abundance of Lonchaeidae was higher in the upper traps at the edges of the forest. This may be due to a preference for larval development in the upper parts of trees, or a preference of adults for tree crowns due to predator pressure in the lower forest tiers, or due to feeding patterns of adults on the resulting tree sap.

Most species of Lauxaniidae occur in forests, on shrubs, trees and foliage, more often in moist habitats. They are less common in dry and wet meadows (Bern-hard, 2004; Dvořáková, 2008; Hernández-Ortiz et al., 2022). Larvae usually develop in decomposing leaves, where they can sometimes form tunnels. Other species develop in bird nests (Dvořáková, 2008). Such preferences caused the high abundance of this family exactly in the crowns of trees at the edge of the forest.

Representatives of Dryomyzidae prefer damp habitats, forest ecosystems near bogs, streams and lakes. Often such places are full of plant remains, in which larvae find substrates for feeding. Adults are saprophagous and can also feed on tree sap (Mathis & Sueyoshi 2011;

Hagenlund, Kvifte, 2015). This is why Dryomyzidae abundance was higher inside forests at low altitudes.

Odiniidae are represented by forest inhabitants. The larvae are zoophagous, predatory, saprophagous, and they often inhabit galleries of wood-boring beetles (Krivosheina, 1979; Gaimari, Mathis, 2011). Interestingly, Stork (1991) found Odiniidae in the canopy of lowland tropical forests. Barkley (2009) also found that Odiniidae were more abundant in canopies. Von Tschirnhaus (2008) collected Odinia specimens in window traps high in the forest canopy in Germany. Thus, our data confirm the studies of the above authors and show that Odiniidae prefer the forest canopy at forest edges.

The larvae of Aulacigastridae develop on the flowing sap of various trees. Adults can be found on the bark of trees (Roháček, 2013). In Europe, Aulacigaster species produce two generations every year, and adults of the second generation overwinter in tree hollows (Roháček, 2013). The abundance of Aulacigastridae in our surveys was higher in upper traps at the edges of forests. Larvae and adults of Periscelididae are associated in their biology with the resulting sap of deciduous trees (oak, elm, poplar, etc.) (Mathis, Rung, 2011). Larvae of many species develop in this sap and adult flies feed on it. Papp (1998) observed that adults often fly to another tree at a height of 3 m when startled. In our studies, the highest abundance of Periscelididae was obtained at edges in the crowns of trees, which is consistent with the observations of Papp (1998).

Milichiidae is one of the families, with total numbers exceeding 1000 specimens in all plots. The larvae of Milichiidae are saprophagous or sapronecrophagous. They consume decaying plant materials. They are found under the bark of trees damaged by other insects, in the passages of beetles and other insects (Xi et al., 2018; Krivosheina, Krivosheina 2019). Adults prefer tree crowns at the edges of forests.

Chloropidae occurred in small numbers. They accounted for the main share in plot1. The food preferences of Chloropidae larvae vary widely: there are sapro-phages, phytophages using both woody and herbaceous plants, some feed on other invertebrates (Nartshuk 2014). Chloropidae have been reported to constitute a higher proportion of the community in open stands and edges than in closed crowns (Allgood et al., 2009). According to our data, Chloropidae prefer tree crowns at edges. Representatives of the family Heleomyzidae are usually forest species. Their larvae are saprophagous, mycetophagous, coprophagous and necrophagous. A few species are also phytophagous. Larvae often develop in bird nests and vertebrate burrows

(Dvořáková, 2008; Preisler, Roháček, 2012). Representatives of this family favoured the ground layers of edge habitats.

Drosophilidae is one of the families, the total number of all plots exceeded 1000 specimens. Representatives of Drosophilidae feed on plant sap, decaying fruits, vegetables and decaying fungi. Larvae inhabit a wide variety of decaying substrates (Rice et al., 2017; Gornostaev et al., 2022). Some studies (de Souza Amorim et al., 2022; Gornostaev et al., 2023) have shown that there is some vertical stratification of this family in temperate forests. Although the abundance of Drosophilidae was higher in upper traps within the forest, the results differed between plots. We assume that there is some species specificity in the distribution of Drosophilidae species, which requires a separate study.

Anthomyiidae is one of the families, with total numbers exceeding 1000 specimens in all plots. Anthomyiidae larvae are mainly phytophagous, saprophagous or omnivorous, feeding on tree sap, with some species parasitising invertebrates (Rotheray, 2019). Anthomyiidae have been shown to be captured in highest numbers in the undergrowth layer (Maguire et al., 2014). In our studies, Anthomyiidae abundance was higher in upper traps in the understory. Fanniidae and Muscidae are two more families, with total numbers exceeding 1000 specimens in all plots. The biology of representatives of these families is very diverse. Adults may feed on nectar, pollen, plant residues, and many are haematophagous. Similarly, larvae are found on a wide variety of substrates (Allgood et al., 2009; Sorokina, Pont, 2011). In our studies, both families were most abundant at the edges of forests in the upper traps, but in the forest interior their abundance was higher in the lower traps. Calliphoridae is one of the families, the total abundance in all plots exceeded 1000 specimens.Larvae of this family feed on carrion, live on decomposing corpses of vertebrates or are parasites of invertebrates (Rognes, 1987; Matuszewski, Mądra-Bielewicz, 2021). Apparently, this is why adults in our studies preferred lower traps, both at the edges and in the forest interior. The abundance of Calliphoridae was always higher at the forest edges, which was previously pointed out by other authors (Gadelha et al., 2015).

Most larvae of Sarcophagidae and Tachinidae are parasites, parasitoids or predators of relatively few vertebrate and invertebrate species. Adult flies often feed on flowering plants (Szpila et al., 2015; Krčmar 2023). In our studies, both families showed the same pattern: their abundance was always higher in the forest edges than in the forest interior.

Some experiments have shown that plant diversity has a significant positive effect on insect diversity and abundance (Scherber et al., 2014). It is possible that this is the reason for the increased abundance of Diptera at the edges of forests. Moreover, this effect was most evident in plot1, where forest ecosystems are not disturbed by anthropogenic activities. Thus, the

Diptera community was more abundant in a natural undisturbed ecosystem than in any of the modified types of open ecosystems. Diptera are among the fastest invertebrates that actively utilise suitable habitat. The flying ability of many families is very high and theoretically they can penetrate deep into forest ecosystems for considerable distances. However, this is not the case in most ecosystems and there is a well-defined pattern of open and closed ecosystem use (Jokimäki et al., 1998; Hughes et al., 2000; Deans et al., 2005). The response of Diptera on edges is influenced by a variety of factors: habitat patch size, ecosystem isolation, edge permeability, edge orientation relative to the sun, landscape composition, adjacent habitats, etc. (McGeoch, Gaston et al. (McGeoch and Gaston 2000; Dantur et al., 2010; Scherber et al., 2014). Our results showed that the maximum Diptera abundance was observed at the edges. The total Diptera abundance was influenced not only by the distance from the forest edge to the forest interior but also by the height of the trap location.

Conclusion

There are 28 families in Diptera studies at edges and different altitudes in deciduous forests of temperate zones. Nine families (Tipulidae, Anisopodidae, Lonchaeidae, Milichiidae, Drosophilidae, Anthomyiidae, Fanniidae, Muscidae, Calliphoridae) accounted for 93.3% of all Diptera in all plots. Of these families, Families Tipulidae, and Drosophilidae were the most abundant in lower traps within forest ecosystems. Families Lonchaeidae, Milichiidae, Anthomyiidae, Fanniidae, and Muscidae were the most abundant in upper traps in forest edges. The families Anisopodidae, and Calliphoridae were the most abundant in the lower forest edges. Differences in species composition were obtained among the study plots. These differences may be due to the open ecosystems adjacent to the plots, the presence of second and herbaceous understorey, and the possibility of species penetration deep into the forest.

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