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Research Article

The selected insect families and their seasonal dynamics in the Mordovia State nature reserve in the burned areas of 2021

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Abstract

Forest fires are one of the main environmental factors that change the habitat and initiate the change of new forest communities. Burned areas are habitats representing a wide range of ecological niches, which can be used by many species of insects. It is especially interesting to observe the restoration processes in the burned areas in the first years after the fires. In 2021-2022, on the territory of Mordovia State Nature Reserve, studies were conducted on the plots that had been burned in 2010 and 2021. Traps with bait based on beer and sugar were used for the study. Our results indicate that the largest number of flying insect forms in the first year after the fire was higher in unburned areas, and the parts of burnt areas located in the depths of the burned territory had the smallest number. The number of beetles was greatest in areas which were not affected by fire. Lepidoptera immediately returned to the site of the fire in 2021. Already the next year their number became much higher. There was no clear dependence on Hymenoptera. The number of Neuroptera and Blattodea was higher in the burned areas of 2010. The seasonal dynamics of Coleoptera in the hot springs was one-peak, whereas in unburned areas it is usually two-peak.

Keywords: insects, forest fire, abundance, severity of forest fire

Introduction

It is well known that forest fires are one of the main and historically natural factors of the formation of forest ecosystems and their constant dynamics, a factor of successional changes (Artsybashev, 2014; Niklasson, Granström, 2000; Zaitsev et al., 2016; Kastridis et al., 2022). A forest fire can dramatically change landscapes and restructure ecological communities on various scales (Filimonova, 2021; Schowalter, 2012; Elia et al., 2012; Chornous, 2022). There are different ways ecosystems respond to fire. Various studies show that the rate of recovery and the types of plants capable of repopulating the territory after a fire depends on the severity of the fire, as well as on the distance between the burned area and the refugium (unburned areas) that provide a source of distribution (Turner et al., 1998; Certini, 2005; Lentile et al., 2007; Hanula et al., 2012; Gongalsky, 2017). Changes in ecosystems that occur after fires largely depend on the intensity of the fire (Buddlea et al., 2006). During ground fire, only the lower tier of the forest burns out greatly, first of all, the grassy tier and the forest floor. Under these conditions, invertebrates die both from the fire itself and from being deprived of the necessary resources (Niklasson, Granström, 2000; Gongalsky, Persson, 2013; Atutova, 2023). During crown fire, the entire ecosystem is disrupted and all tiers of the forest are destroyed. It often happens that the forest does not die immediately during a fire but during further seasons. The diversity and abundance of invertebrate species are significantly reduced in such badly burned areas (Koltz et al., 2018).

Insects are the most important members of forest communities, they play a key role in the nutrient cycle, pollination, water filtration and biological control, and they also serve as food species for larger fauna (Dedyukhin, 2022; King et al., 2013; Asbeck et al., 2021; Barkalov, Khruleva, 2021; Duffus et al., 2021; Seibold et al., 2021). Insects are one of the most numerous and diverse groups on the planet, but little is known about their response to forest fires of varying intensity and frequency (Geraskina et al., 2021; Perov, Aleksanov, 2022; Gustafsson et al., 2019; Certini et al., 2021; Mason et al., 2021; Wagner et al., 2021; Supartha et al., 2022). In some cases, individual groups of insects thrive after a particular heat wave. It has been found that many insects avoid fire by flying, jumping or crawling ahead of the flame or burrowing into the soil to escape from the flame on the surface (McCullough et al., 1998; Wikars, 2002; Campbell et al., 2007; Lazarina et al., 2019). How a group of insects reacts to fire is determined by their life history and adaptation, whether fire is widespread in their habitat and whether food sources remain after. The egg stages and insect larvae are more vulnerable to fire, as they have limited mobility and certain habitat requirements (Ruchin et al., 2021; Kastridis et al., 2022). Adult insects can avoid fire more effectively, as well as repopulate areas after burning. It was found that the timing of the prescribed fire significantly affects the composition of the insect community, often summer fires contribute to a greater variety of predatory and phytophagous (Johnson et al., 2008; Hanula et al., 2012; Harris, Taylor, 2015).

According to historical documents and observations of Mordovia State Nature Reserve employees, fires of different sizes and intensities were recorded on its territory in 1842, 1899, 1932, 1972, 2010, 2018, 2019 and 2021 (Kupriyanov, Novenko, 2021; Kharitonova, 2021; Sieber et al., 2013; Ruchin et al., 2019). The largest forest fires were observed in the summer of 2010 and 2021. After 2010, successional ecosystem changes took place on the site of the burned areas, but such changes differed greatly in different places. Thus, in many cases, the emergence of undergrowth and the restoration of the grassy tier occurred at the sites of low-intensity ground fires. The most significant changes were noted in the burned areas that were formed on the site of high-intensity crown and ground fires. In these places, after 2010, there was a gradual fall of dead and weakened trees (Khapugin et al., 2016). This contributed to the cluttering of the territory, the appearance of dry wood mainly coniferous species. In addition, small-leaved growth appeared in such places, mainly birch, aspen, and alder in moistened places. Dry deadwood, small-deciduous growth, dry-hardy trees (birches and pines) and dry weather eventually gave the effect of a “powder keg”. This is a kind of “triad” of natural factors influencing fires (Agee, 1996; Cochrane, 2009). In 2021, fires occurred on the site of the areas burned in 2010. In many places, the fires of 2021 destroyed all the dead wood

The work aims to study the number and dynamics of flying insects (excluding Diptera) in the Mordovia State Nature Reserve at the sites of fires in 2010 and 2021. Beer traps were used for this purpose.

Material and methods

This study was conducted at the Mordovia State Nature Reserve (center of European Russia). The Mordovia State Nature Reserve is located on the southern border of the taiga natural zone (54°42' – 54°56'N 43°04' – 43°36'E). The total area is 32162 hectares. Forest communities occupy 89.3% of the total area of the reserve. Soils are classified as predominantly sandy with varying degrees of podzolization. Sandy peat-podzolic soils are also widespread on sands with a fairly high groundwater level. Sandy podzolic soils are located under deciduous forests. The average annual precipitation ranges from 406 to 681 mm. The average annual air temperature is 4.7°C. The maximum temperature values are recorded in July, and the minimum values are recorded in February. The vegetation cover is similar to the taiga complex with some features of nemoral communities.

The material for the study was collected in April–October 2021 and 2022 using beer traps (Ruchin et al., 2020). For this purpose, 5-liter plastic containers with a cut-out window were used. The luring agents were beer mixed with sugar. Such traps were installed on tripods at a height of 1.5 m from the soil surface. A total of 11 traps were installed at different sites (Table 1).

Table 1. A brief description of the studied plots in the places of installation of traps (Appendix 1)

Plots	Description
1	Burned area in 2010 In 2021, it was not exposed to fire. A significant amount of dead wood, and dry-hardy trees (pine and birch). Dense undergrowth of birch. Shrubs are mainly represented by raspberries. The grassy tier is sparse. The litter is small from birch litter.
2	Burned area in 2010 In 2021, it was not exposed to fire. It is located 10 m from the edge of the fire in 2021. A significant number of deadwoods, and dead-hardy trees (pine and birch). Dense undergrowth of birch. Shrubs are mainly represented by raspberries. The grassy tier is sparse. The litter is small from birch litter.
3	Burned area in 2010 and 2021 It is located 10 m from the edge of the fire deep into the burnt territory (20 m from plot No. 2). In 2021, the territory was completely burned out. The deadwood and grassy tier are completely burnt out. There were rare dry bushes.
4	Burned area in 2010 and 2021 It is located 1000 m from the edge of the fire deep into the burned area. In 2021, the territory was completely burned out. The deadwood, birch, shrubs and grassy tier were completely burned out.
5	Burned area in 2010 and 2021 It is located 2000 m from the edge of the fire deep into the burned territory. In 2021, the territory was completely burned out. The deadwood, birch, shrubs and grassy tier were completely burned out.
6	Burned area in 2010 and 2021 It is located 1500 m from the edge of the fire deep into the burned territory. Lowland with water (wet biotope). In 2021, there was a low-intensity fire in this place. Fallen trees and rare birch undergrowth, left over from the fires of 2010, have been preserved. The grassy tier almost completely burned out in 2021 (there were small curtains of cereals).
7	Burned area in 2010 and 2021 It is located 10 m from the edge of the fire deep into the burnt territory (20 m from plot No. 8). In 2021, the territory was on fire. The deadwood, birch, shrubs and grassy tier were partially burned out. At least half of the dead wood and a lot of dense dry birch undergrowth remained.
8	Burned area in 2010 In 2021, it was not exposed to fire. It is located 10 m from the edge of the fire in 2021. A significant amount of large deadwood, and dry-hardy trees (pine and birch). Very dense undergrowth of birch and aspen. The grassy tier is sparse. The litter is small from the fall of hardwoods.
9	Burned area in 2010 and 2021 It is located 10 m from the edge of the fire deep into the burnt territory (20 m from plot No. 10). In 2021, the territory was on fire. The deadwood, birch, shrubs and grassy tier were partially burned out. At least half of the dead wood and dense dry birch undergrowth remain.
10	Control. A plot of forest that has not been exposed to fire. It is located 10 m from the edge of the fires of 2010 and 2021. Old mixed forest of pine, and birch with an admixture of linden, rowan, birch bark, and bird cherry (in the second tier). The litter is well-defined and powerful, the grassy layer is sparse.
11	Control. A plot of forest that has not been exposed to fire. It is located 500 m from the edge of the fires of 2010 and 2021. Old mixed forest of pine, and birch with an admixture of linden, rowan, birch bark, and bird cherry (in the second tier). The litter is well-defined and powerful, the grassy layer is sparse.

Thus, the installation of traps was carried out on a control plot (old mixed forest) and experimental ones, which differed in distance from the edge of fires in 2021, cluttered and intensity of burnout in 2021.

Two trap expositions were made at 11 plots (22 samples) immediately after the elimination of fires from September 11, 2021 (until October 11). In 2022, 13 trap exposures were made at the same 11 plots (143 samples). When analyzing the results, only data on the quantitative parameter (number) of individuals of flying insect forms in traps during exposure were used. Flightless forms (for example, ants) were not taken into account. However, when describing the results, we made some notes about the number of ants, which seemed interesting to us (but these data were not summed up in the calculations and tables). Exposure time is the period between hanging the trap and sampling for analysis (expressed in days). The definition of the species was not carried out within the framework of this study.

Results

In total, in 2021, 816 individuals from 6 insect orders were captured and noted (Table 2). In 2021, traps were installed immediately after the official elimination of fires. In areas not affected by fires, the number of insects in September and October 2021 was about 45-70% lower compared to the same periods in 2022. This was especially true for butterflies and Hymenoptera. The numbers were influenced by the conditions of the hot summer and the lack of forage plants, many of which dried up in August.

Table 2. The total number of different insect orders in traps at individual plots in 2021

Order	Plots											Total
	1	2	3	4	5	6	7	8	9	10	11	
Blattodea	1	0	0	1	0	0	0	0	0	0	2	**4**
Heteroptera	0	0	0	0	1	0	0	0	0	0	0	**1**
Neuroptera	5	0	0	4	0	1	0	0	0	2	1	**13**
Coleoptera	2	2	0	2	1	6	4	2	3	5	9	**36**
Lepidoptera	152	43	86	68	12	18	20	18	22	133	136	**708**
Hymenoptera	3	1	1	3	2	7	2	2	8	14	11	**54**
Total	**163**	**46**	**87**	**78**	**16**	**32**	**26**	**22**	**33**	**154**	**159**	**816**

As we pointed out above, ants were not taken into account in our studies (they were not included in the tables). However, it must be noted that they were present in the traps. They were especially numerous at the plots 3, 4, 5, 6, 7. According to our previous studies of 2019-2022, such ants in beer traps is usually a characteristic of the early spring period, when they are lured to a sugar-containing liquid (Popkova et al., 2021). It was unusual to find flying insect forms in plots 4, 5 and 6 (1-2 km from the edge of the fire) in 2021. For example, there were not much fewer butterflies 1 km from the edge of the fire (plot 4) than at the edge itself. However, we should point out that these plots were mainly marked by large species from the families Noctuidae, and Geometridae, and there were no small species from the families Tortricidae, Pyraustidae, or Phycitidae. In 2022, seasonal studies were conducted on the same plots. From April to October, 20242 individuals from 9 insect orders were captured (Table 3).

Table 3. The total number of different insect orders in traps at individual plots in 2022

Order	Plots											Total
	1	2	3	4	5	6	7	8	9	10	11	
Blattodea	73	9	3	1	0	2	11	22	0	1	30	**152**
Heteroptera	2	1	1	5	3	2	2	2	2	1	0	**21**
Rhaphidioptera	3	0	0	0	0	0	0	5	0	1	0	**9**
Neuroptera	238	45	27	45	25	38	52	47	16	97	27	**657**
Coleoptera	884	529	333	293	178	358	738	939	678	1097	1195	**7222**
Lepidoptera	1593	1219	733	821	577	548	670	885	762	1405	1438	**10651**
Hymenoptera	142	214	159	116	68	89	169	167	92	134	163	**1513**
Mecoptera	0	0	0	0	0	0	0	8	0	0	0	**8**
Trichoptera	0	0	0	0	0	1	2	1	3	1	1	**9**
Total	**2935**	**2017**	**1256**	**1281**	**851**	**1038**	**1644**	**2076**	**1553**	**2737**	**2854**	**20242**

The basis of the insect population was represented by the orders Lepidoptera (52.6%), Coleoptera (35.7%), Hymenoptera (7.5%) and Neuroptera (3.2%). The remaining orders were a very small part of the fauna in terms of numbers and were marked by single individuals. The highest number of Lepidoptera was obtained in plots 1, 11 and 10, respectively, by 15.0, 13.5 and 13.2% of the total amount of this group for the year. The smallest number of individuals was registered in plots 6 and 5, respectively, 5.1 and 5.4%. The highest number of Coleoptera was typical for plots 11 and 10, respectively, 16.5 and 15.2% of the total amount of this group for the year. The smallest number of specimens of this group were caught in plots 5 and 4, respectively, 2.5 and 4.1%.

Representatives of the order Hymenoptera were caught in the largest number at plot 2 (14.1%), and the least of them were caught at plot 5 (4.5%). However, in other plots, the number of this group was quite stable. The maximum number of Neuroptera was recorded in plot 1 (36.2%), and the minimum – in plot 9 (2.4%). Thus, the highest number of flying insects in beer traps for the 2022 season was detected at plots 1, 11 and 10, and the smallest – at plots 5 and 6. Representatives of Blattodea were present at plots in small numbers. However, the largest number of this group was recorded in Plot 1 (48.0%) and Plot 11 (19.7%). Isolated instances were noted in the depths of burned areas.

Seasonal insect activity was determined by the example of the three most widespread orders – Coleoptera, Lepidoptera and Hymenoptera. Coleoptera had one peak in abundance, which was recorded in June (Fig. 1). It is important to note that only at plot 11 a second smaller peak in abundance was also detected at the end of August

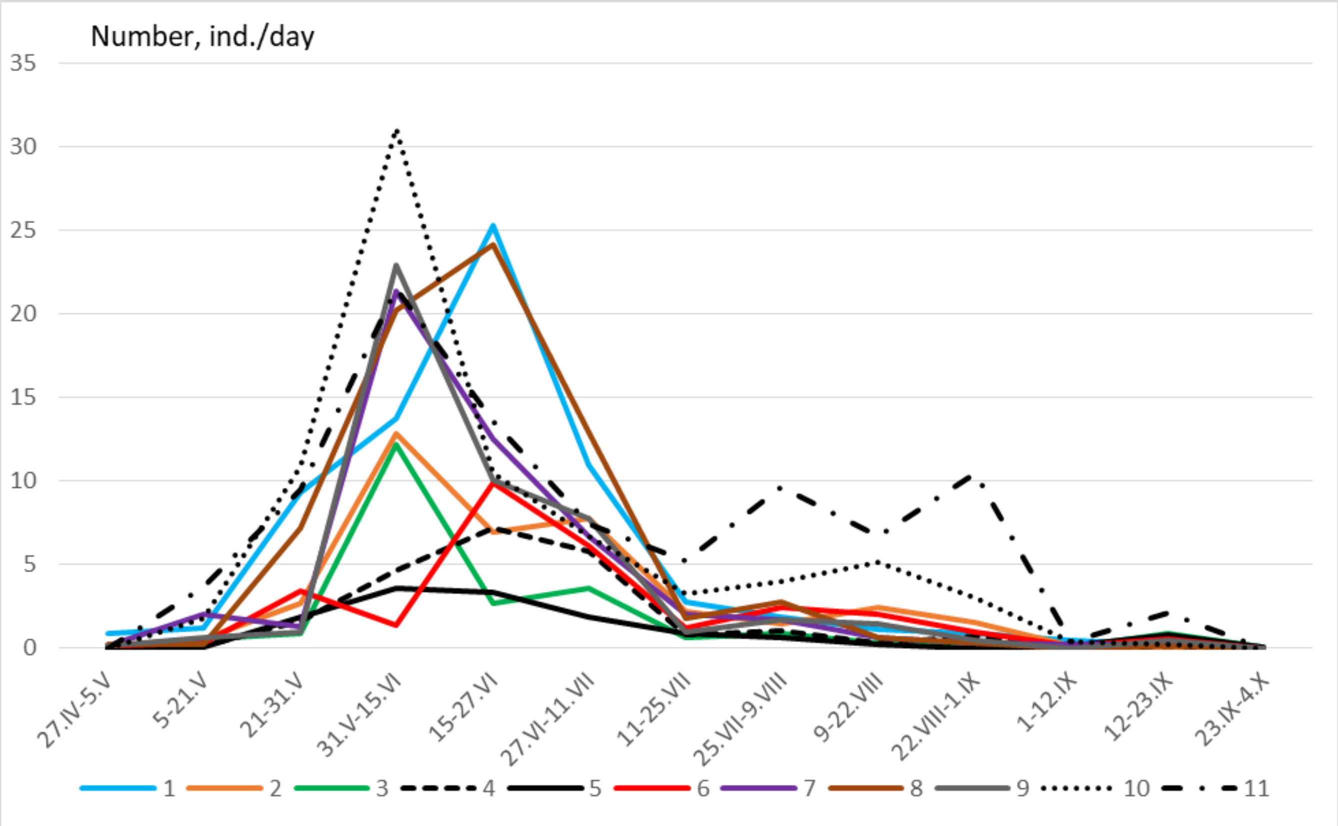

Figure 1. Seasonal dynamics of Coleoptera abundance in experimental plots in 2022

The number of Lepidoptera gradually increased during the season in all plots (Fig. 2). The maximum numbers were obtained in the middle and second half of August (a slight increase in numbers was also observed in the second half of June). At the beginning of September, there was a sharp decline in the number of butterflies in all plots.

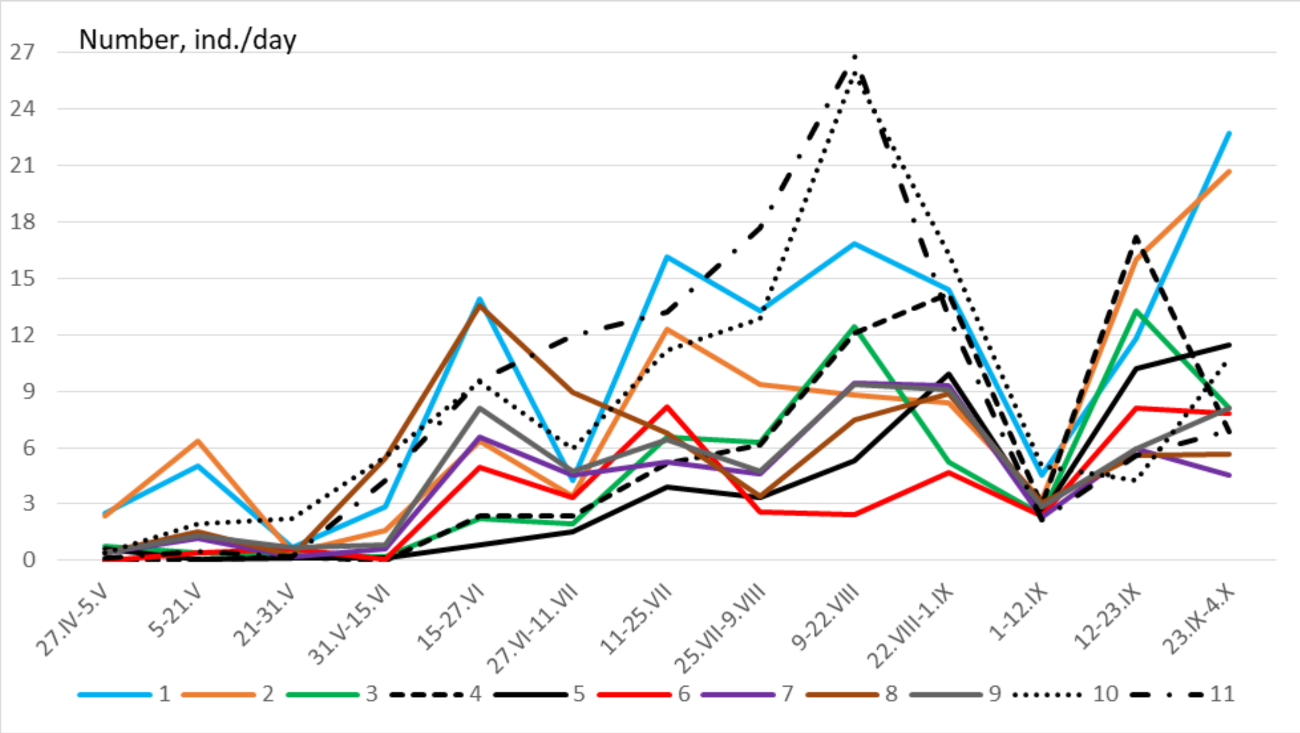

Figure 2. Seasonal dynamics of Lepidoptera abundance in experimental plots in 2022

Seasonal activity of Hymenoptera in 2022 had a two-peak character (Fig. 3). The first increase in the number occurred in late May and early June, and the second more significant increase was observed in August and early September. In May, mid-summer and the second half of September, the lowest numbers of Hymenoptera were recorded at the plots.

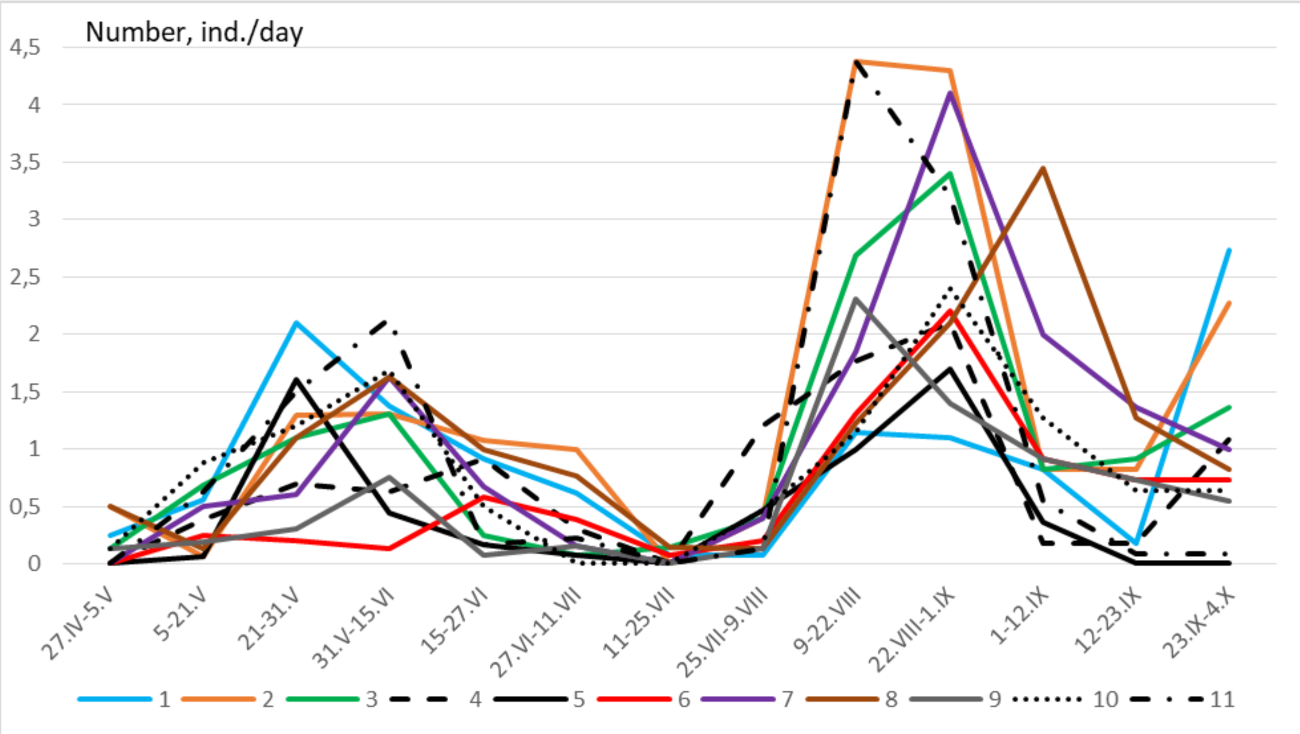

Figure 3. Seasonal dynamics of Hymenoptera abundance in experimental plots in 2022

Discussion

The resilience of forest communities to catastrophic natural phenomena largely depends on the heritage in the form of local biota and its adaptation, as well as on climate variability and the interaction between various disturbances (Johnstone et al., 2016). In the fire zone, ticks, collembolans, shell amoebas, insects and earthworms, i.e. groups closely related to the organogenic horizons of the soil, are massively dying. More active insect groups are more resistant to fires, for example, flying forms (Wikars, Schimmel, 2001; Moretti et al., 2006). The intensity and frequency of fires affect the possibilities of restoring plant communities subsequently, the number and safety of refugiums for invertebrates, the availability of food resources, and interspecific interactions (Bess et al., 2002; Chia et al., 2015; Gongalsky, 2017; Ward et al., 2020). Thus, the way the plant community reacts to the fire determines which entomofauna can be seen later in the burned areas. Therefore, after a certain time, there is a restoration of biodiversity in ecosystems affected by fires. In each case, the process of restoring biodiversity takes a different time (Moretti et al., 2006; Kral et al., 2017).

In total, for the 2022 season, representatives of 4 orders (Lepidoptera, Coleoptera, Hymenoptera and Neuroptera) differed in the largest number of traps. Normally, these groups are found in beer traps by other researchers (Makarkin, Ruchin, 2021; Ruchin, Egorov, 2021; Allemand, Aberlenc, 1991; Ribeiro et al., 2012; Ruchin et al., 2020, 2021b). Our results indicate that the largest number of flying insect forms in the first year after the fire was higher in the unburned areas, and the plots in the depths of burned areas had the lowest numbers.

The highest number of Coleoptera was typical for areas of old mixed forests (plots 10 and 11). The smallest number of specimens of this group were caught at the plots of fires in 2021 far from their edges. It often happens that an increase in the number of dead wood, stumps, snags and dead trees after a fire contributes to a high number of xylophages and saproxyl insects. Some beetles are attracted to smoke after a fire because they lay eggs in freshly burned wood to provide a competitive advantage over other xylophagous insects (Evans, 1972; Wikars, 2002; Boulanger, Sirois, 2007). For example, the remains of birch logs and stumps had the most diverse fauna on the burned plot (Wikars, 2002). It is possible that it was the dry branches, logs and stumps that remained due to the humidity of the biotope on plot 6 (located in the depths of the burned areas) that contributed to the greater number of Coleoptera, unlike plots 4 and 5, where the fire destroyed almost all plant resources. There was a high number of beetles at the end of May and June on plot 10 compared to plot 11. Both plots are forest ecosystems untouched by the fires of 2010 and 2021. However, plot 11 is located deep in the forest, and plot 10 is on the border with the burned area, i.e., in fact, on the edge of the forest. Apparently, in this case, the number of beetles was higher due to the pubescent effect (Maguire et al., 2016).

In 2021, immediately after the fire, the number of Lepidoptera in the burned areas located in the depths at a distance of 1-2 km was significantly reduced compared to the control areas. However, in the plots located inside the burned areas, but close to the edge of the fire, the number was similar or even higher. Laboratory experiments have shown that after direct exposure to fire on soil samples, butterfly caterpillars (Noctuidae and Pyralidae) are destroyed (Gongalsky et al., 2012). Thus, the appearance of adult forms of butterflies immediately after fires in these areas indicates active migration and the ability to quickly populate the burned areas shortly of some families of this order.

In 2022, the highest number of Lepidoptera was also obtained in unburned areas, and the smallest number of individuals were recorded in areas located deep in the burned areas. However, for comparison, we would like to point out that in 2021, in the areas farthest from the edge of the fires (5 and 6), the number of butterflies was 7-12% lower than in the unburned areas (1 and 11). In 2022, the number in plots 5 and 6 compared to plot 1 was already 46-62%, and in comparison with plot 11 it even exceeded. These are data from the results of processing autumn collections in September and October 2021 and 2022. According to some data, lepidoptera often react poorly to the death of vegetation after a fire, but react more positively to fires of low intensity if there are enough shelters and resources (Adedoja et al., 2019; Lazarina et al. 2019).

Representatives of the order Hymenoptera were caught in the largest number at plot 2, and there were the least of them at plot 5. In other plots, the number of this group was fairly uniform and stable. There was no special dependence. For Spheciformes wasps, local ecological conditions, the availability of trophic resources, nesting sites and the availability of prey for feeding larvae depend on climatic conditions and time after a fire (Cruz-Sánchez et al 2011). Predatory and social wasps effectively use places after a fire if there are sufficient resources and habitat conditions for building nests and foraging. These groups often use dry wood pulp to build nests and use pollen from flowers and other arthropods for food (Ruchin et al., 2021c). The observation of a significant number of ants in traps installed specifically in the burned areas of 2021 can be explained by the lack of protein nutrition facilities for this group. In addition, the presence of ants in traps located 1 and 2 km from the edge of the fire indicates the ability of this group to find shelter from the elements and continue the normal life of the colony after its termination. Other authors also paid attention to the outbreaks of the number of ants on the burned places in the first years after the fires. This is attributed to the appearance of wood residues after fires and the good adaptation of ants to xerophilic conditions (Krugova, 2010; Bess et al., 2002; Sackmann, Farji-Brener, 2006). At the same time, high-intensity crown fires harm ants (Arnan et al., 2006).

From the order Neuroptera, traps with beer bait usually attract Chrysopidae, whose adults feed mainly on pollen and honeydew, but not predators (Makarkin, Ruchin, 2020, 2021). Chrysopidae of these genera are mainly dendrobionts; they live on various deciduous trees and shrubs (less often on pines), not giving preference to any genera and species. Forest edges are usually hotspots of Chrysopidae species diversity. In addition, the species diversity of this family often increases in post-pyrogenic habitats (Duelli et al., 2002, 2019; Ruchin et al., 2021c). However, in our studies, it is difficult to give an accurate assessment of the degree of fire impact on Neuroptera for the first year after fires. The number of Blattodea was higher in the 2010 hot springs and unburned areas, and only single specimens were found in the burned areas of 2021. Typically, this group has such a dependence: the number is higher in native or fire-restored ecosystems (Abbott, 1984; Teasdale et al., 2013).

Seasonal dynamics of Coleoptera in local temperate forests usually have two population peaks, which are recorded in May-June and the end of August (Ruchin et al., 2018, 2021a; Ruchin, Egorov, 2022). Such dynamics is typical for non-affected forest ecosystems. That is why two population peaks were registered on plot 11. The second late-summer increase in the number was determined by beetles from the family Nitidulidae. Only one peak in numbers was visible in the burned areas, and the second one was not recorded. Presumably, the first peak is associated with the dispersal of xylophages and phytophages (families Elateridae, Cerambycidae and Scarabaeidae), which do not participate in the second peak of abundance.

In temperate forests, the seasonal dynamics of Lepidoptera are influenced by photoperiod and temperature (Zografou et al., 2014; Colom et al., 2021). The seasonal dynamics of Lepidoptera abundance had a gradual increase until the middle and second half of August with a slight increase in the second half of June. At the beginning of September, there was a sharp decline in the number of butterflies. Perhaps this is due to very dry weather in this period of 2022. On the other hand, we recorded similar dynamics of peaks and falls in the number of butterflies in 2020 in other places of the Mordovia State Nature Reserve in completely different biotopes and under different temperature circumstances (Ruchin, 2021). The results obtained may be some internal mechanisms of the cyclical development of butterflies in the region, which are only modified by climatic factors. The general trend indicates an increase in the number of butterflies in traps in the second half of summer and autumn, whereas in spring the number of

Lepidoptera in beer traps is extremely small. In temperate latitudes, the abundance of Hymenoptera increases sharply in the middle of the season and reaches a maximum in late July and early August (MacDonald, Matthews 1981; Ulyshen et al., 2011). In our studies, similar results have been obtained.

Conclusion

Thus, taxa vulnerable to fires eventually return to the fire zone, while taxa adapted to fires remain. However, in the first year after the fires, the largest number of flying forms of insects was higher in the unburned areas, and the depths of burned areas had the lowest numbers. The insect community seems to be recovering after the fire, and some groups of flying insects return more readily than others. Even far enough from the edge of the fire (1.5–2 km), the number of insects increases due to actively flying forms. The number of beetles is greatest in areas where there were no fires. Lepidoptera immediately returned to the plots of the fire in 2021. The following year their number became much higher. However, it has not yet returned to its original values, apparently due to the lack of food plants for adults and larvae. There was no clear dependence on hymenoptera. The number of Neuroptera and Blattodea was higher in the areas of areas burned in 2010, where, along with a good shrub layer, the illumination is much higher. The seasonal dynamics of Coleoptera in the burned areas in the first year is modified and differ from native ecosystems (one-peak versus the usual two-peak).

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Appendix 1. Photos of the studied plots in September 2021 (left) and August 2022 (right)

Plot 1

Plot 2

Plot 3

Plot 4

Plot 5

Plot 6

Plot 7


Plot 8


Plot 9


Plot 10

Plot 11