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IMPACT OF FIRES ON THE HYMENOPTERAN FAUNA IN THE CENTER OF EUROPEAN RUSSIA FOREST ECOSYSTEMS

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ABSTRACT

Forest fires have a significant impact on ecosystems. The impact of fires in the natural ecosystem of the Mordovia State Nature Reserve (European Russia) using beer traps was investigated. Insects were sampled from burned and unburned (control) plots and compared abundance and diversity (11 plots in total). For sampling, beer traps were used, which were placed on tripods at a height of 1.5 m above the soil surface. Beer with sugar was used as bait. Collections were made from April to October 2022 and 2023 after 7-16 days, when insect activity was highest. As a result of material processing, 3416 specimens from two infraorders, two suborders, and 11 families were examined. The studied plots differed in species diversity and abundance of Hymenoptera that were captured using beer traps. During two years of our research, representatives of two infraorders, two suborders, and 11 families were identified. In the first year after large-scale fires, representatives of only seven families were observed, whereas in the second year, 11 families were observed. The abundance of all Hymenoptera was also higher by 25.8% in the second year after fires. It was shown that different species of Vespidae responded differently to fires. The major recolonization of the burned plots occurs in the second year after the fires.

Keywords: Insects, species composition, wildfire, Vespidae

ABSTRAK

Kebakaran hutan mempunyai kesan yang besar terhadap ekosistem. Menggunakan perangkap bir, kajian kesan kebakaran dalam ekosistem semula jadi, Rizab Alam Semula Jadi Mordovia (Rusia Eropah) telah dijalankan. Sampel serangga telah dikumpulkan daripada plot (kawalan) yang terbakar dan tidak terbakar dan membandingkan kelimpahan dan kepelbagaian (11 plot keseluruhannya). Untuk pensampelan, perangkap bir yang diletakkan pada tripod pada ketinggian 1.5 m di atas permukaan tanah telah digunakan. Bir dengan gula digunakan sebagai umpan. Pengumpulan telah dijalankan dari April hingga Oktober 2022 dan 2023 selepas 7-16 hari, apabila aktiviti serangga paling tinggi. Hasil daripada pemprosesan bahan pensampelan, sebanyak 3416 spesimen daripada dua infraorder, dua suborder dan 11 famili telah diperiksa. Plot yang dikaji berbeza dalam kepelbagaian spesies dan kelimpahan Hymenoptera yang ditangkap menggunakan perangkap bir. Dalam dua tahun penyelidikan, wakil dua infraorder, dua suborder dan 11 famili telah dikenal pasti. Pada tahun pertama selepas kebakaran berskala besar, hanya tujuh famili serangga telah direkodkan, manakala pada tahun kedua, 11 famili telah direkodkan. Kelimpahan semua Hymenoptera juga lebih tinggi sebanyak 25.8% pada tahun kedua selepas kebakaran. Telah diperhatikan bahawa spesies Vespidae yang berbeza bertindak balas secara berbeza terhadap kebakaran. Penjajahan semula utama plot yang terbakar berlaku pada tahun kedua selepas kebakaran.

Kata kunci: serangga, komposisi spesies, kebakaran hutan, Vespidae

INTRODUCTION

Temperate forest ecosystems make up a significant portion of our planet's forest resources. They provide vital ecological, natural and economic resources for fauna, flora and humanity. However, climate changes have largely begun to affect the structure and functioning of these forests. Some of the destructive factors are fires, which are most often associated with anthropogenic activities. Forest fires severely affect energy fluxes and biogeochemical cycles in temperate forest ecosystems (Atutova 2023; Guo et al. 2016; Veselkin et al. 2022; Zimov et al. 1999). Statistically, most fires in all countries are caused by human fault. The reasons that cause fires include careless handling of fire on vacation, hunting, wood production, forest cutting, transportation on rail, and arson (Mollicone et al. 2006; Perevedentsev et al. 2022; Ruchin et al. 2019; Tiberio et al. 2022).

In conditions of increasingly frequent fires, the main issue arises in the subsequent restoration of ecosystems after pyrogenic influence. In all ecosystems, arthropods are the most abundant and diverse group of invertebrates, participating in many terrestrial food webs (Dole et al. 2023; Idris et al. 2023; López-Rojas et al. 2023; Sánchez-Bayo & Wyckhuys 2019; Vasenkova & Kuznetsova 2022). They play an important role in the decomposition of organic matter and in the pollination of plants. Many herbivorous species cause measurable damage in ecosystems. Parasitic species can benefit humans by destroying agricultural pests (Bennett & Hobson 2009; Dedyukhin 2023; Dvořák et al. 2023; Shenoy et al. 2011; Vorobjeva & Chertoprud 2023; Zouaimia et al. 2022). Thus, the functions of arthropods in ecosystems are extremely diverse.

Among insects, the order Hymenoptera is exceptionally diverse in species composition and extremely important for all ecosystems. Species from this order are found in all terrestrial ecosystems and perform many functions. For example, predatory and parasitic Hymenoptera regulate the reproduction of phytophagous species. Hymenoptera are also the best-known pollinators of plants (Forbes et al. 2018; Ruchin et al. 2022a, 2022b; Steffan-Dewenter & Tscharntke 2002). Due to the significant influence of Hymenoptera on other trophic levels, they were identified as key species in ecosystems (LaSalle & Gauld 1991). The species diversity and abundance of Hymenoptera in natural ecosystems can reach a high level. In this regard, fires can have an impact on the fauna of this order. For example, certain species of Vespidae at plots subjected to low-intensity ground fires are more abundant than in control unburned plots, while at plots with crown fires the biodiversity and abundance of Hymenoptera are insignificant (Ruchin et al. 2021). Quite a significant amount of studies is devoted to the reactions of ants to exposure to fires. A review of such publications (Andersen 2019) shows that the greatest variation in ant community composition occurs in habitats managed with highly contrasting fire regimes. The most susceptible to direct death from fire are ants that nest on flammable substrates (leaves, branches, tree trunks). On the other hand, species richness and community abundance are shown to increase in the first years after the

fire (Moretti & Barbalat 2004; Moretti et al. 2009; Mola & Williams 2018). The recent fire was found to have no apparent impact on species composition, richness or community structure. In general, bee communities from burned and unburned plots were similar. These results suggest that native bee communities may be resilient to low-intensity fires (Simmons & Bossart 2020). In the forests of North America, the biodiversity and richness of bees were highest in plantations one year after the fire (Gelles et al. 2023). Another study found that the effect of fire on Hymenoptera was most evident in communities in the first years after the fire. But the exception was repeated fires, which had a negative impact (Carbone et al. 2019).
Research on the impact of the consequences of the large fire that occurred in August 2021 on the territory of the Mordovia State Nature Reserve was conducted. The aim of the work was to study the diversity and abundance of Hymenoptera attracted by beer traps in the first and second years after the fire.

MATERIALS AND METHODS

Sampling Sites

In 2022 and 2023, the research was conducted in the forest ecosystems of the center of European Russia (Republic of Mordovia). This is the territory of the Mordovia State Nature Reserve. There were wildfires here in 1842, 1899, 1932, 1972, 2010, 2019, and 2021 (Kharitonova & Kharitonova 2021; Ruchin et al. 2019). In 2021, the fires were particularly severe, but the intensity and severity of the wildfire varied. As a result, the 2021 fires occurred at the 2010 burned plot and therefore completely destroyed all deadwood. The Mordovia State Nature Reserve is located on the southern boundary of the taiga zone (Figure 1). Forest communities before the fires of 2010 and 2021 occupied almost 90% of the area. The main forest forming species is pine (*Pinus sylvestris* L.). After the fires and destruction of pine forests, birch forests of *Betula pendula* Roth began to develop in many places. The average annual precipitation ranges from 406 to 681 mm.

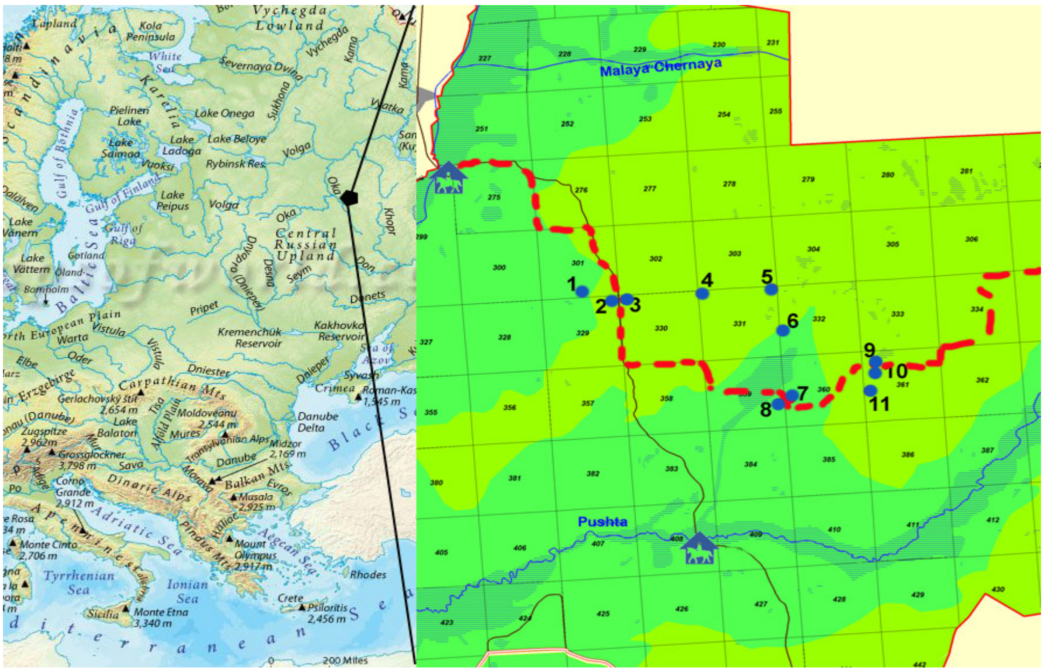


Figure 1. Geographical position of the Mordovia State Nature Reserve in Europe. The stuied plots are indicated by blue dots and numbers. The red dotted line shows the boundaries of the fires of 2021

Insect Sampling
The material was collected using beer traps as baits, the construction of which was described previously (Ruchin et al. 2020; Ruchin et al. 2023). Sugar was added for digestion. Collections were made from April to October 2022 and 2023, when insect activity was highest. Each trap was set at a height of 1.5 m on a tripod. One beer trap for each plot was set up. A total of 11 plots were selected (Figure 1), which differed in the degree of fires, distance from the fire edge and vegetation overgrowth after the 2010 fires. A detailed description of the plots was made earlier (Ruchin 2024).

Species Identification
All specimens collected were transferred from beer traps to plastic bags containing 70% ethanol. The specimens were sorted and then identified in the laboratory. A total of 3,416 specimens were identified and analyzed. Where possible, identification was carried out to the species or genus level (Parasitica were identified only to the infraorder). Seasonal dynamics of abundance was determined as a sum for the whole order.

Data Analysis
To determine differences in abundance among Vespidae a PCA (principal component analysis) was conducted, with species abundance as response variables and trap location as outcome variables. All statistical analyses were performed using Paleontological Statistics Software Package for Education and Data Analysis (PAST) 4.11 software (Hammer et al. 2001). To analyze the results, only quantitative data in traps during exposure were used. Exposure time is the period between hanging the trap and sampling for analysis (measured in days). Vespidae were chosen as a model for numerous families because they are well baited by beer traps. The analysis was done only for species that had a representative sample.

RESULTS

As a result of processing the material for 2022 and 2023, representatives of two infraorders, two suborders, 11 families were identified (Table 1). In 2022, representatives of only 7 families were recorded, while in 2023 there were 11 families (additionally, Halictidae, Melittidae, Pompilidae, Tiphiidae were recorded). The abundance of all Hymenoptera also varied by year and was 25.8% higher in 2023 (Table 1). Vespidae is the family with the highest abundance, 86.6% in 2022 and 73.3% in 2023.

Table 1. Taxonomic diversity and specimens of Hymenoptera at all plots over the research period in 2022 and 2023 (number of specimens is indicated for each year)

Suborder, Family, Species	2022	2023	Total Number of Specimens
Symphyta			
Tenthredinidae	4	14	18
Andrenidae	3	13	16
Apidae			
Apis mellifera Linnaeus, 1758	3	44	47
Bombus sp.	120	257	377
Halictidae			
Sphecodes sp.		2	2
Melittidae		35	35

Crabronidae			
Bembix rostrata (Linnaeus, 1758)		1	1
Crossocerus sp.	3		3
Ectemnius sp.	1	7	8
Mellinus sp.	52	43	95
Sphecidae			
Ammophila sp.	3	5	8
Podalonia sp.		9	9
Chrysididae			
Chrysis sp.	1	7	8
Pompilidae			
Ceropales sp.		1	1
Tiphiidae			
Tiphia sp.		4	4
Vespidae			
Discoelius sp.	10	29	39
Dolichovespula media (Retzius, 1783)	58	41	99
Dolichovespula saxonica (Fabricius, 1793)	130	77	207
Polistes dominula (Christ, 1791)	17	92	109
Polistes nimpha (Christ, 1791)	185	744	929
Symmorphus sp.	20	14	34
Vespa crabro Linnaeus, 1758	287	195	482
Vespula germanica (Fabricius, 1793)	143	66	209
Vespula rufa (Linnaeus, 1758)	29	23	52
Vespula vulgaris (Linnaeus, 1758)	431	113	544
Parasitica	13	67	80
Total number of specimens	1513	1903	3416
Number of species	6	11	

Differences in the abundance of Hymenoptera were also observed at different plots over the years (Figure 2). An increase in the abundance of Hymenoptera in 2023 was observed at five plots: plot1, plot3, plot4, plot5, plot6. Of these, the last four plots are the places of severe fires in 2021 and in these places, there was no vegetation left after the fires (especially in plot4, plot5, plot6).

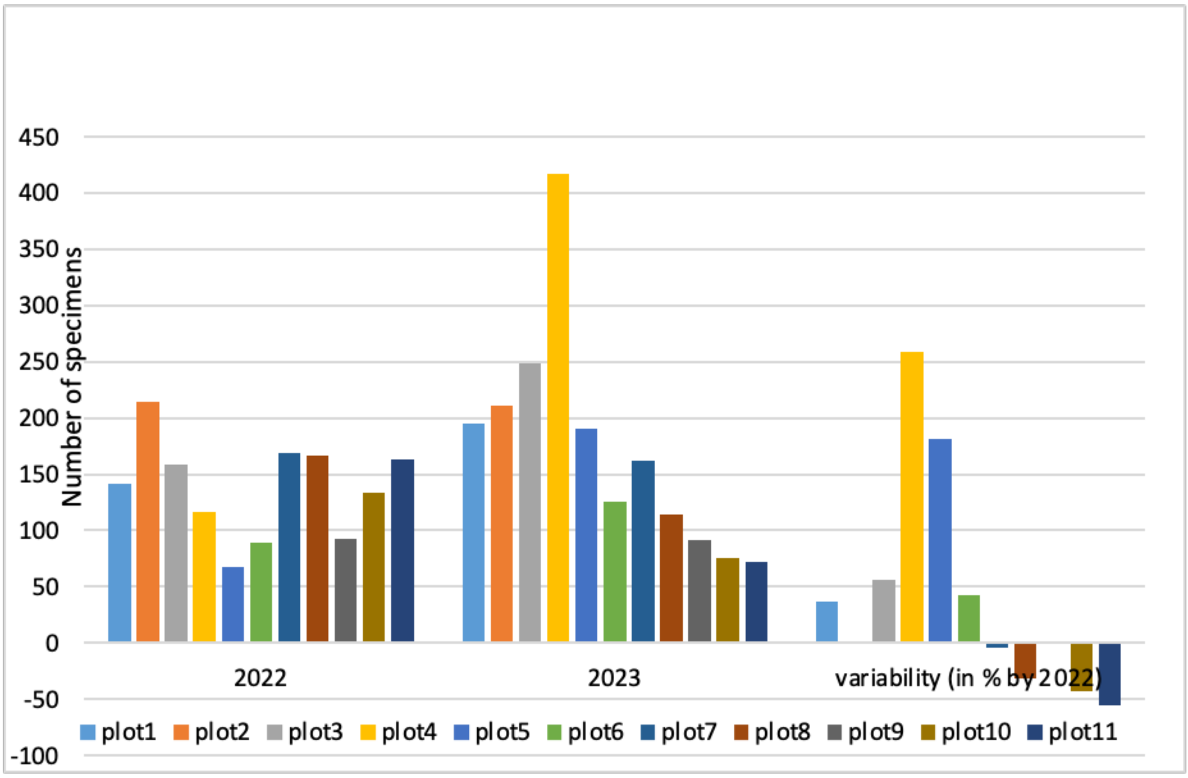
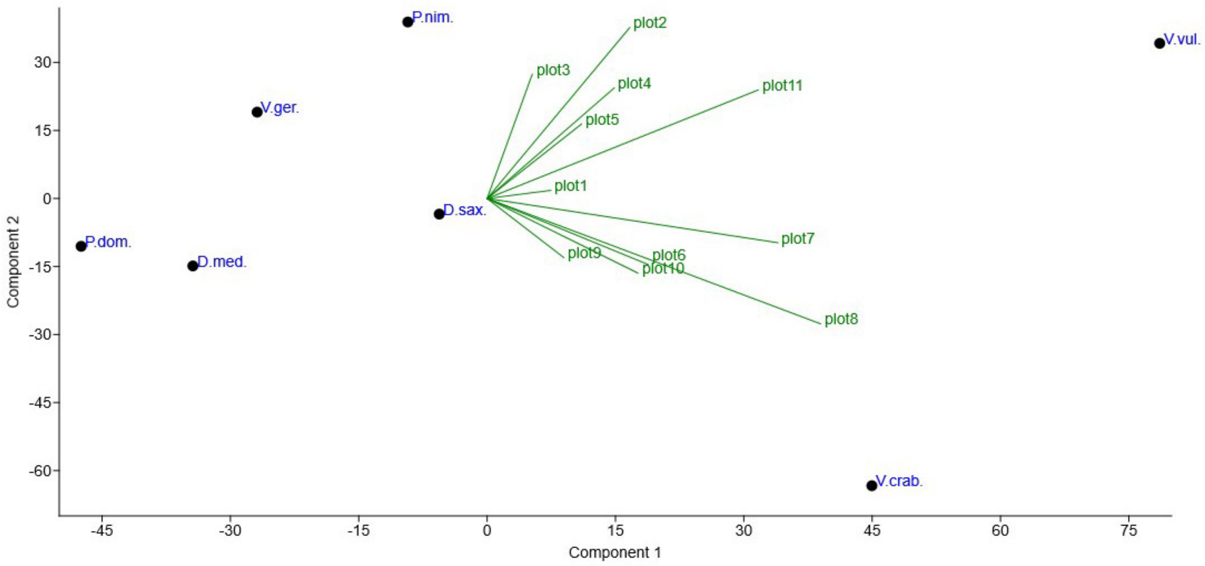


Figure 2. Total Hymenoptera number and its variability at all plots during the research period. The X-axis indicates the years of research, the Y-axis indicates the number of specimens

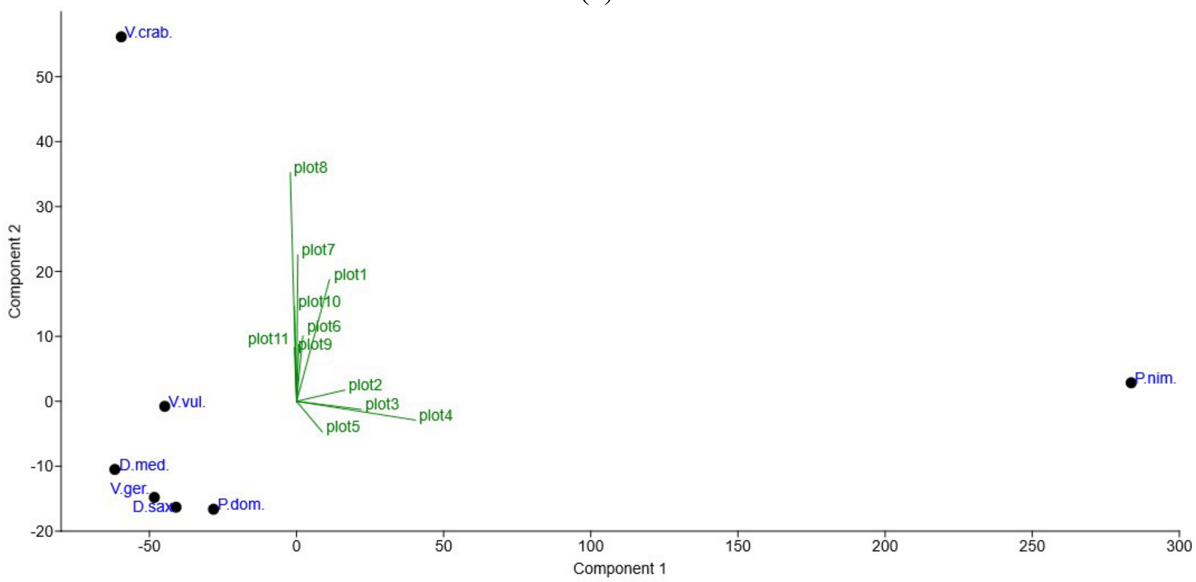
A significant decrease in Hymenoptera abundance in 2023 was recorded at plot8, plot10 and plot11. This effect depended on the abundance of several Vespidae species. For example, the abundance of Vespula vulgaris decreased significantly at all plots. This may be due to a less favorable year for the development of this species. The abundance of *Vespa crabro* was consistently low in both years of the research at plot2–plot5 (these are burned plots or adjacent to them). At the same time, it decreased at other plots. The abundance of *Vespula germanica* was high in 2022 at plot2–plot5 and in 2023 it decreased significantly at these plots. The abundance of *Dolichovespula saxonica* increased slightly in 2023 at plot2–plot6, but at the remaining plots we observed a decrease in abundance.

An increase in the total number of individuals of almost all families in 2023 is noteworthy. Thus, the abundance of Tenthredinidae and Andrenidae increased by 3.5 and 4.3 times, respectively. The abundance of Apidae increased by 2.4 times. The abundance of the most numerous family Vespidae increased to a lesser extent – by 1.1 times.

Among Vespidae species, *Polistes dominula*, *Polistes nimpha* were observed to increase in 2023. At the same time, the total number of the species *Dolichovespula saxonica Vespa crabro*, *Vespula germanica*, *Vespula vulgaris* decreased. At the same time, *Dolichovespula media* and *Vespula rufa* did not experience any significant change in abundance. For Vespidae, a PCA of abundance was carried out depending on the plots (Figure 3). The abundance of all species except *Vespula vulgaris* and *Vespa crabro* appeared to be evenly distributed across the plots in 2022. The abundance of *Vespula vulgaris* increased at plot2–plot7, plot11 (more towards plot11). The abundance of *Vespa crabro* also increased at the same plots, but most of all at plot8.



(a)



(b)

Figure 3. The principal component analysis (PCA) ordination diagram of the selected Vespidae species based on their abundance at various studied plots: a – 2002; b – 2023. Short designations: D.med. – *Dolichovespula m*edia; D.sax. – *Dolichovespula saxonica*; P.dom. – *Polistes dominula*; P.nim. – *Polistes nimpha*; V.crab. – *Vespa crabro*; V.ger. – *Vespula germanica*; V.vul. – *Vespula vulgaris*

In 2023, the abundance of *Vespula vulgaris* and other species, except *Vespa crabro* and *Polistes nympha*, remained uniform. The abundance of *Vespa crabro* remained quite high at plot6–plot10, while the abundance of *Polistes nympha* was largely shifted towards plot1–plot5, where the abundance of these species prevailed. seasonal dynamics showed a number of features that are characteristic of Hymenoptera in temperate zone ecosystems. Two main abundance peaks were recorded in 2022 (Figure 4).

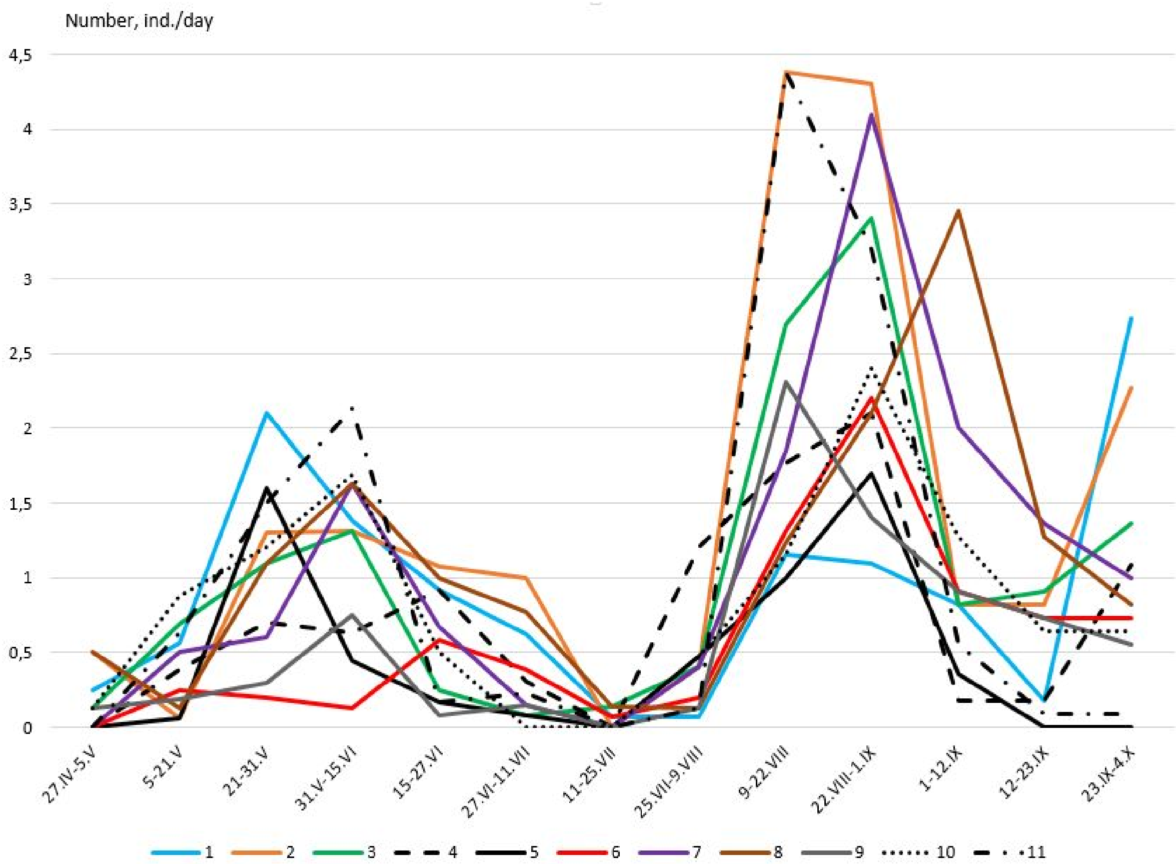


Figure 4. Seasonal dynamics of the total number of Hymenoptera at plots in 2022. The X-axis indicates the trap exposure dates in 2022, the Y-axis indicates the number of specimens (in ind./day)

The first smaller maximum was obtained in late May–early June. The second more significant maximum was typical in August. There was also a slight increase in Hymenoptera abundance in early October. The minimum abundance values of Hymenoptera were obtained in July. For all plots, the seasonal dynamics were identical.

In 2023, the seasonal dynamics were approximately similar and there were also two maxima and one significant minimum in July. However, for some plots, seasonal dynamics values were obtained that differ from other plots (Figure 5).

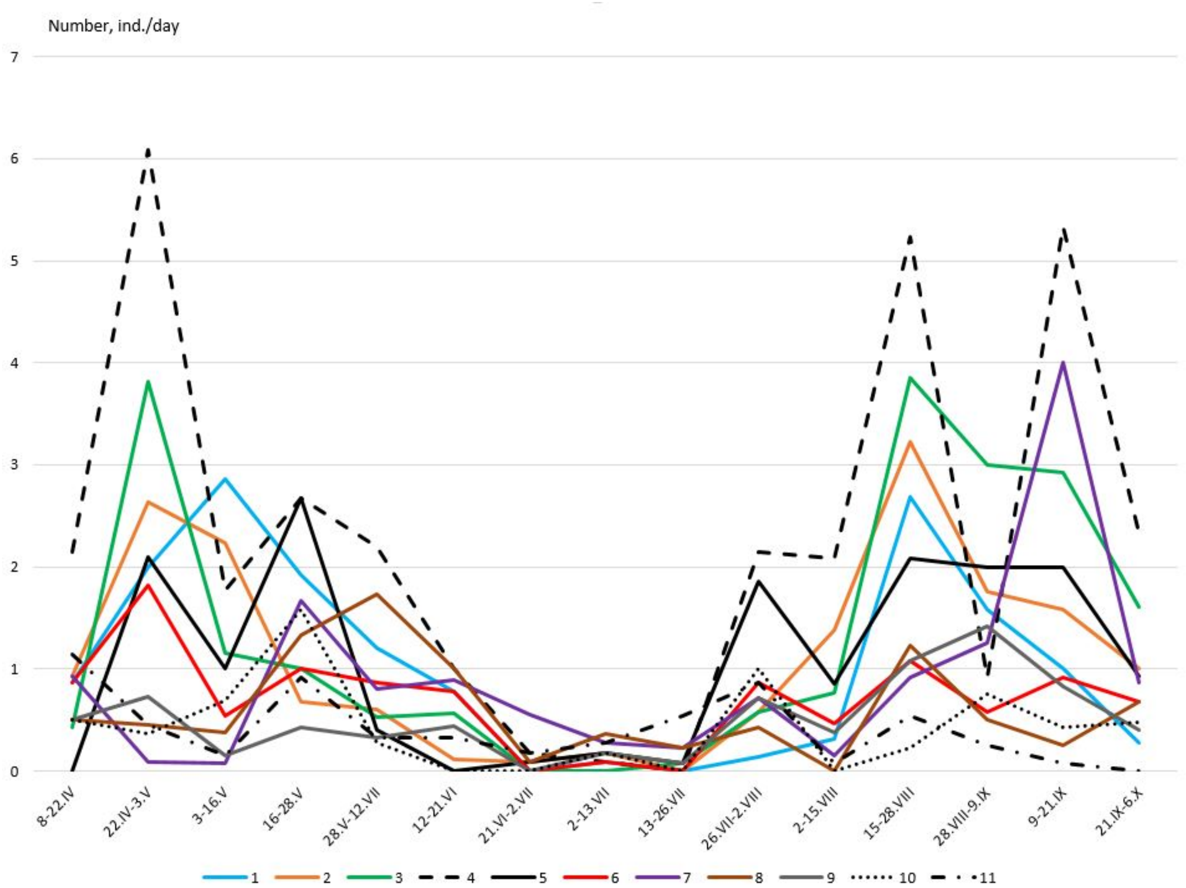


Figure 5. Seasonal dynamics of the total number of Hymenoptera at plots in 2023. The X-axis indicates the trap exposure dates in 2022, the Y-axis indicates the number of specimens (in ind./day)

Thus, we observed several maxima at plot4, where maximum increases in the abundance of individuals were obtained (Figure 2). The highest maximum was observed at the end of April, and then smaller maxima were obtained in the second half of August and at the end of September. There was also a small abundance peak in the second half of May. Two maxima were also obtained at plot7, but they were shifted in time unlike the other plots. At plot5, the highest peak was obtained at the end of May, a slightly smaller peak was observed in early August and then in September. Thus, in 2023, the seasonal dynamics of Hymenoptera abundance was not the same for all plots and certain individual differences were obtained at many plots.

DISCUSSION

A fire is generally expected to alter pollinator abundance and diversity through direct and indirect effects. A fire of varying severity can kill insects, causing a temporary decrease in abundance and gradual recovery (Moylett et al. 2020). On the other hand, a ground fire destroys bushes and old herbs. This produces better transparency for flowering herbaceous plants, creating a flower-rich habitat that may attract or support more pollinators than shady, unburned habitats (Hanula et al. 2016; Moretti et al. 2009; Moylett et al. 2020). Several Hymenoptera species showed that species richness and community abundance increase in the first years after the fire (Banza et al. 2021; Gelles et al. 2023; Moretti et al. 2009; Simmons & Bossart 2020). For example, many species of bees and wasps were found to respond early and late, but maximum species diversity was achieved 3 years after the fire (Bogusch et al. 2015). In 2022, in the first year after the fires, herbaceous vegetation was practically absent at the burned plots and began to appear only in the second half of the forest (Ruchin 2024). This explains the low abundance of pollinators in 2022 – *Apis* and *Bombus*. After herbs and partly flowering shrubs began to appear at the burned plots, *Apis* and *Bombus* abundance increased significantly. In addition, dispersal distance of Apidae is determined by flight ability, which is higher in larger species such as *Bombus* (Guédot et al. 2009; Ne'eman et al. 2000). This explains why large *Apis* and *Bombus* in 2023 appeared in large abundance on flowering plants at plot4, plot5, plot6, which are located quite far from the fire edge (1–2 km).

In the Czech Republic, a highly dynamic community of Hymenoptera was found at the fire plots that used burned forest plantations 1-7 years ago (Bogusch et al. 2015). Apparently, our research also observed a dynamic community that responded to changes in the environment. This is particularly evident in the diversity of Hymenoptera abundance dynamics in the second year after the fire in 2023. It was clearly unstable and varied significantly at individual plots. For example, a significant increase in the abundance of Hymenoptera at plot4 was due to *Polistes nympha* (Figure 3). Plot4 is located 1 km from the fire boundary and from plot2 and plot3, which were on the boundary. Considering that the activity of this species is quite high, it can be assumed that its individuals gradually spread into the depths of the burned plots. This is what is confirmed by several peaks in the abundance of the species during the season. There was a flight of young individuals from nests and their spread to the burned plots. This pattern is also confirmed by the abundance of *Polistes nimpha* in plot5 (plot was 1 km from plot4), which increased slightly later than the abundance in plot4 (Figure 4). Wasps of the genus *Polistes* (*Polistes nimpha* and *Polistes dominula*) build nests under branches of shrubs. They prefer open, well-warmed biotopes (Mielczarek et al. 2021). They feed mainly on caterpillars (Sumner & Cini 2021). It is pointed out that Polistes females usually fly close to the nest. At the same time, as predators they are very active in penetrating other territories to find food (Sumner & Cini 2021). The emergence of herbaceous plants in 2023 at the burned plots, where caterpillars can develop as a major food item for *Polistes*, caused this effect.

The beer traps we used are well suited for studying social wasps from the family Vespidae (Dvořák & Landolt 2006; Dvořák 2007; Komonen et al. 2020; Maciel et al. 2023; Sorvari 2013). As we noted above, the abundance of the mentioned species was quite high and this family dominated the traps. This family is quite demanding in terms of habitat. They need open and sunny areas to search for food and build nests (Kasper et al. 2008; Richter 2000). Very often they return to places with a large food supply, in search of optimal food sources (Richter 2000).

Vespula vulgaris is an oligoeurythermic species that is rare in southern parts of Europe. This species dominates in open habitats (Dvořák & Landolt 2006; Dvořák 2007). It builds nests mainly in underground cavities (usually abandoned mammal burrows) or in wall cavities and under various buildings. Prey includes various dipterans. The family development cycle is long – from May to October (Edwards & Telfer 2002). A significant increase in abundance was obtained in 2022, with higher abundance at the burned plots than in the unburned forest. *Vespa crabro* – very common throughout Europe, with the exception of the UK. It usually builds nests in shelters: in tree hollows, in mammal burrows, in attics and other places. Prey includes various insects from large dipterans to honey bees and bumblebees. The family development cycle is long – from May to October (Edwards & Telfer 2002; Nadolski 2013; Ruchin et al. 2022a). *Vespa crabro* abundance was consistently low in both years of the research at the burned plots. Apparently, *Vespa crabro* abundance was reduced at these areas with low numbers of prey (*Apis* and *Bombus*) and few suitable habitats. *Dolichovespula media* makes nests openly hanging in the middle or upper tiers on branches of trees and shrubs or under eaves of buildings. Prey is mainly various Diptera. The family development cycle is short – from late May to August (Dvořák et al. 2008; Ruchin & Antropov 2019). The abundance of the species was very low in both years of the research at the burned plots. This may be due to the lack of suitable nesting sites, as trees and large shrubs were absent at these plots. *Vespula germanica* is also a common species attracted to beer traps. It usually builds nests in underground cavities or under buildings. Prey – various Aranei, Diptera, Coleoptera, Hymenoptera. The family development cycle is long – from May to October (Edwards & Telfer 2002; Sackmann et al. 2000). In 2022, the abundance of this species along with *Vespula vulgaris* was higher at plot2-plot5 than in 2023, while at the other plots it remained equally low in both years of the research. Both species prefer to build nests in underground cavities, which may have contributed to the similar results obtained. *Dolichovespula saxonica* builds nests openly hanging on branches of trees and shrubs, as well as in shelters (in outbuildings, attics). The prey *Dolichovespula saxonica* are mainly various Diptera (Ruchin & Antropov 2019). The family development cycle is short – from May to August. The abundance of the species in 2022 was higher at the unburned plots, plot10 and plot11. However, single specimens were recorded the following year, and an increase in the abundance was recorded at plot3-plot5. Also, an increase in the abundance of this species was observed at the burned forest plots in Sweden (Johansson et al. 2020). *Vespula rufa* is found sporadically in beer traps. It builds rounded nests in cavities under tree roots or in abandoned mammal burrows. The prey of *Vespula rufa* are various Diptera. The family development cycle is short – from May to the end of August (Archer 2007). In both years of the research, the abundance of *Vespula rufa* was higher at plot2, plot3, plot4.

In the forest ecosystems, after large-scale, catastrophic fires, there are fewer untouched areas of habitat, which is crucial for the subsequent restoration of individual species (Brennan et al. 2011; Blomdahl et al. 2019). After fires, recolonization of flying insects usually occurs on the side of the unburned perimeter and insects move gradually inside the burned plot (Gustafsson et al. 2019; Johansson et al. 2020). However, the ability of insects to detect a suitable habitat is limited by distance as well as food resources, shelter availability, accessibility and breeding opportunities. Long distances to isolated habitats and the absence of flowering plants reduce the abundance of pollinators. Large completely burned plots create sharp transitions between unburned forest ecosystems and burned plots according to the principle of ecotones. Such ecotones can slow down or prevent insects from dispersing deeper into burned plots. Large-scale fires also increase the risk of recolonization failure (Collinge & Palmer 2002; Haynes & Cronin 2006; Nimmo et al. 2019; Olson & Andow 2008).

Based on our results, we observed the recolonization of Hymenoptera to burned plots as early as the next year after large-scale fires. However, a limited contingent of the Hymenoptera species community moves to these plots. But already in the second year after the fires, an increase in the abundance of species and families of Hymenoptera is observed, i.e. the diversity of communities at burned plots increases. Other authors observed something similar in bee communities, when species diversity and abundance increased in the first year after the fires (Gelles et al. 2023). Such plots are especially actively inhabited by bees that nest on the ground in open and sunny places and woody materials. The authors recognise this as an unsurprising phenomenon given the high availability of herbaceous flowering plants, open sandy plots and deadwood immediately after a fire (Vidal-Cordero et al. 2023).

CONCLUSION

The studied plots differed in species diversity and abundance of Hymenoptera, which were caught using beer traps. Over two years of our research, representatives of two infraorders, two suborders, and 11 families were identified. In the first year after large-scale fires, representatives of only 7 families were recorded, while in the second year there were 11 families. The abundance of all Hymenoptera was also higher by 25.8% in the second year after the fires. At the same time, Vespidae is the family that was most represented by social active species. It was shown that different species of Vespidae responded differently to the fires. The main recolonization of the burned plots occurs in the second year after the fires. To better understand the impacts of catastrophic fires, additional studies on insect responses are needed, along with efforts to identify vulnerable species and communities, and assessments of adaptive capacity under changing fire regimes.

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AUTHORS DECLARATIONS

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Conflict of Interest
The authors declare that they have no conflict of interest.

Ethics Declarations
No ethical issue is required for this research.

Data Availability Statement
My manuscript has no associated data.

Authors' Contributions
All data is received by the author.

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