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Post-Fire Changes of the Neuropteran Assemblages in Forests of the Mordovia Nature Reserve

V. N. Makarkin[a], * and A. B. Ruchin[b], **

[a] *Federal Scientific Center of the East Asia Terrestrial Biodiversity, Far Eastern Branch, Russian Academy of Sciences, Vladivostok, 690022 Russia*

[b] *Joint Directorate of the Mordovia State Nature Reserve and National Park "Smolny", Saransk, 430005 Russia*

**e-mail: vnmakarkin@mail.ru*

***e-mail: ruchin.alexander@gmail.com*

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Abstract—We examined neuropteran assemblages of the Mordovia Nature Reserve collected in 2022 and 2023 using bait traps at the site of 2021 and 2010 fires and in areas not exposed to these fires. We found that the fires, in which almost all vegetation was destroyed, had different effects on different ecological groups of Neuroptera. Fires were favorable for chortobiont (herb-dwelling) species (e.g., *Chrysopa abbreviata*, *Ch. walkeri*, *Ch. commata*) and species preferring forest edges (e.g., *Apertochrysa prasisa* and *A. ventralis*) which increased their numbers. Such fires were, however, very unfavorable for dendrobiont (tree-dwelling) species, especially e.g., *Nineta alpicola*, *N. vittata* and *Chrysotropia ciliata*, which disappeared from burned areas or were unable to restore their numbers in this time.

Keywords: Neuropteran assemblage, Mordovia Nature Reserve, fires

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INTRODUCTION

Catastrophic events in natural ecosystems have increasingly occurred in recent decades due to climate change. Floods, hurricanes, tsunamis and other events can seriously alter these ecosystems. One such catastrophic factor is fire. At the same time, they are often considered as a common environmental factor since long before the appearance of humans, especially in arid regions (Sannikov, 1981; Odum, 1986; Shubin and Zalesov, 2016; Tiberio et al., 2022).

Fires have significant impacts on energy and matter flow in temperate forest ecosystems (Inbar et al., 2020; Geraskina et al., 2021; Vilkova et al., 2023; Atutova, 2023). In such ecosystems, arthropods are the most numerous and diverse group of invertebrates involved in many food webs. They play an important role in the decomposition of organic matter, cause harm as phytophages, destroy pests, participate in plant pollination as well as performing other functions in ecosystems (Chernyshev, 1996; Schowalter, 2016).

The impact of forest fires on arthropods, especially insects, has been studied extensively and in different aspects (e.g., McCullough et al., 1998; Moretti et al., 2006; Krugova, 2010; Gustafsson et al., 2019; Sheehan and Klepzig, 2021; Thompson et al., 2022). However, we are aware of only three publications studying the impact of forest fires on the species diversity and abundance of Neuroptera (Duelli et al., 2019a, 2019b; Ruchin et al., 2021).

The aim of our work was to study the abundance and diversity of Neuroptera in the Mordovian Nature Reserve using bait traps in the first and second years after the 2021 fires (early post-fire assemblage), 12–13 years after the 2010 fire (late post-fire assemblage) and in forests not exposed to fires to better understand the dynamics of the restoration of natural neuropteran assemblages after fires.

MATERIALS AND METHODS

The study was carried out in the center of the European part of Russia, in the Mordovia Nature Reserve (Republic of Mordovia). The reserve is located at the southern border of the taiga zone with elevation up to 190 m above sea level. These are natural ecosystems with Scotch pine (*Pinus sylvestris* L.) as the main forest tree. In the Mordovia Nature Reserve, serious forest fires were observed in 1842, 1899, 1932, 1972, 2010, 2019 and 2021 (Ruchin et al., 2019). Before the fires of 2010 and 2021, forests occupied almost 90.3% of the area. However, after the fires, birch forests of *Betula pendula* Roth began to develop in many places. The fires were especially intense in 2021. The intensity and severity of the forest fires varied across different parts of the protected area. In 2021, fires occurred on the

(a) (b) (c)

Fig. 1. Early post-fire landscape after the 2021 fire (plot no. 3) (a), late post-fire landscape after the 2010 fire (plot no. 8) (b), and a forest not exposed to fires (plot no. 10) (c). All photographs were taken in 2022.

site of the 2010 fires; they completely destroyed all deadwood and dead trees in many places. Only rare bushes and roots remained, which later gave rise to tree shoots (mainly birch and aspen), as well as a very small part of living trees.

The material was collected from April to October in 2022 and 2023 using bait traps, namely crown bait traps (CBTs), the design of which was previously described (Ruchin et al., 2020; Ruchin, 2024). Each trap was installed at a height of 1.5 m on a small wooden tripod, one for each sampling plot (see Ruchin et al., 2023). A total of 11 such plots were selected, which differed in fire intensity, distance from its edge, degree of vegetation restoration after the 2010 fires, and forest areas that were not exposed to fires. Photographs of all plots were published earlier (Ruchin, 2024).

Plot no. 1 (plot 3 in Ruchin, 2024; quarter 301 of the reserve): burned in 2010 and 2021. The trap was located 10 m from the edge of the fire deep in the burned area (20 m from the trap in plot no. 8). In 2021, the area was completely burnt out, including deadwood and herb layer; rare dry (dead) bushes remained.

Plot no. 2 (plot 4 in Ruchin, 2024; (quarter 329): burned in 2010 and 2021. The trap was located 1 km from the edge of the fire in the burned area. In 2021, the area was completely burnt out, including deadwood, birch, shrubs, and herb layer.

Plot no. 3 (plot 5 in Ruchin, 2024; quarter 330): burned in 2010 and 2021. The trap was located 2 km from the edge of the fire deep in the burned area. In 2021, the area was completely burnt out, including deadwood, birch, shrubs, and herb layer (Fig. 1a).

Plot no. 4 (plot 6 in Ruchin, 2024; quarter 331): burned in 2010 and 2021; is characterized by higher humidity than plot no. 5. A humid lowland biotope. The trap was located 1.5 km from the edge of the fire deep in the burned area. In 2021, there was a low-intensity ground fire; living (very rare) and fallen trees and sparse birch undergrowth remaining after the 2010 fire. The herb layer almost completely burned out in 2021, but small clumps of grasses remained.

Plot no. 5 (plot 7 в Ruchin, 2024; quarter 331): burned in 2010 and 2021. The trap was located 10 m from the edge of the fire deep in the burned area (20 m from the trap in plot no. 8). During the 2021 fire, deadwood, birches, shrubs and the herb layer were partially burned out. At least half of the deadwood and a lot of dense dry (dead) birch undergrowth remained.

Plot no. 6 (plot 9 в Ruchin, 2024; quarter 332): burned in 2010 and 2021. The trap was located 10 m from the edge of the fire deep in the burned area (20 m from the trap in plot no. 10). During the 2021 fire, dead wood, birch trees, shrubs and herb layer partially burned out. At least half of the dead wood and dense dry (dead) birch undergrowth remained.

Plot no. 7 (plot 1 in Ruchin, 2024; quarter 360): burned in 2010, but was not exposed to fire in 2021. There is a significant amount of deadwood and dead trees (pines and birches). Many of dry trees have fallen and are on the ground or lying on each other, forming heaps. Birch undergrowth is dense. Shrubs are represented mainly by raspberry. The herbaceous cover is sparse. There is a small amount of litter, consisting mainly of birch leaves.

Plot no. 8 (plot 2 in Ruchin, 2024; quarter 359): burned in 2010, but was not exposed to fire in 2021; similar to plot no. 7. The trap was located in 10 m from the edge of the 2021 fire. There is a significant amount of deadwood and dead trees (pines and birches), and dense birch undergrowth. Shrubs are represented mainly by raspberry. The herbaceous layer is sparse. There is a small amount of litter, consisting of birch leaves (Fig. 1b).

Plot no. 9 (plot 8 in Ruchin, 2024; quarter 361): burned in 2010, but was not exposed to fire in 2021. The trap was located 0 m from the edge of the 2021 fire. There is a significant amount of large fallen trees, as well as dead trees (pines and birches). Undergrowth of birch and aspen is very dense. The herbaceous layer is sparse. There is a small amount of litter, consisting of birch and aspen leaves.

Plot no. 10 (quarter 361): control, not exposed to fires. The trap was located in 10 m from the edge of the 2010 and 2021 fires. It is an old mixed forest of pines and birches with rare lindens, rowan-trees, elms and bird cherries in the second layer. The litter is well defined and thick. The herbaceous cover is sparse.

Plot no. 11 (quarter 361): control, not exposed to fires. The trap was located in 500 m from the edge of the 2010 and 2021 fires. It is an old mixed forest of pines and birches with rare lindens, rowan-trees, elms and bird cherries in the second layer. The litter is well defined and thick. The herbaceous cover is sparse.

The material was sampled 13 times in 2022 and 15 times in 2023, with subsequent data summation. It was identified by the first author using various sources (monographs, keys, articles with descriptions of species, etc.), and is stored at the Federal Scientific Center of the East Asia Terrestrial Biodiversity (Vladivostok).

RESULTS

The neuropteran assemblages one year after the fire are poor in quantitative terms (16–52 specimens per trap in season), but the species diversity (4–9 species per trap in season; in total, 12 species in all 6 plots) was only slightly lower than in the late post-fire (more restored) plots. All traps yielded only two species—*Apertochrysa prasina* and *Chrysoperla carnea*. Of the predatory Neuroptera, 17 specimens of five species (all Chrysopidae) were caught in the traps, including 15 specimens (two species) of chortobionts (herb-dwelling) (*Chrysopa abbreviata*, *Ch. walkeri*, *Ch. commata*).

The neuropteran assemblages two years after the fire have somewhat changed. The number increased (75–146 specimens per trap in season) and the species diversity slightly increased (6–9 species per trap in season; a total of 13 species were collected in all 6 plots). Four species were present in all traps: *A. prasina*, *A. flavifrons*, *A. ventralis* and *Chrysoperla carnea*. The number of predatory Neuroptera increased: 25 specimens of six species (five species of Chrysopidae, one species of Hemerobiidae), including 10 specimens of chortobiont chrysopids.

In total, 891 specimens (an average of 74.3 per trap) and 14 species were caught in all six early post-fire plots over 2 years (2022–2023).

The composition of the neuropteran assemblages 12–13 years after the 2010 fire (plots nos. 7–9) changed little compared to the early post-fire ones: 5–10 species per trap in season (a total of 11 species were collected in 2022 and 2023 each in all three plots; 14 species in 2 years). The average number increased, mainly due to *Apertochrysa prasina*; in total, 1277 specimens were caught in all three late post-fire plots over two years (2022–2023) (an average of 212.8 per trap). All traps contained three species 12 years after the fire (*A. prasina*, *A. flavifrons*, and *Ch. carnea*) and five species 13 years after the fire (*A. ventralis* and *Chrysopa abbreviata* are added). The diversity of predatory Neuroptera was slightly lower: six specimens of four species 12 years after the fire and 23 specimens of two species 13 years after the fire (all Chrysopidae). Chortobionts were represented by eight specimens of two species. A total of 1277 specimens were caught in all three late post-fire plots over 2 years (2022–2023) (an average of 212.8 per trap).

In two control plots not exposed to fires (plots nos. 9–10), the abundance and number of species are approximately the same (slightly lower) as in the late post-fire plots: 30–411 specimens of 6–8 species per trap in season. In total, 568 specimens (on average 142 per trap) and 13 species of Neuroptera were collected in two plots over 2 years. The abundance and diversity of chortobionts are very low: three specimens of two species.

The composition and distribution of species by abundance in the control plot no. 10, located 10 m from the edge of the 2021 fire, and in the late post-fire plot no. 9 are very similar. Whereas in plot no. 11, located far from the fire sites, the total number of lacewings was very low, but dendrobiont (tree-dwelling) species are present (e.g., *Nineta alpicola*), and edge species are very rare (e.g., *Apertochrysa prasina*, *A. ventralis*).

DISCUSSION

The insect order Neuroptera has been studied relatively well in the Mordovia Nature Reserve. In total, 45 species of 49 recorded from Mordovia are known from there (Makarkin and Ruchin, 2014, 2019, 2020, 2021, 2024a, 2024b; Ruchin and Makarkin, 2017; Ruchin et al., 2023). However, the bait traps used in these works do not attract all species. We have previously noted that those species that are not imaginal stage predators, but feed on pollen and nectar of flowers (phytophages) and honeydew secreted by aphids and scale insects (glycophages) are readily attracted by these traps (Makarkin and Ruchin, 2019; Makarkin et al., 2023). These are mainly many green lacewings (Chrysopidae); however, predatory green lacewings, as well as species of other families are rarely attracted. In total, 19 species of green lacewings were caught in our samples using CBT in plots nos. 1–11, of which green lacewings are represent 17 of 21 species recorded from the reserve.

In the first years after a strong crown and surface fire, only herbs, small shrubs, and birch and/or aspen undergrowth grow in the burned areas. Such a landscape is typical for plots nos. 1–3 (Fig. 1a). Accordingly, chortobionts should dominate there. Indeed, dendrobionts such as *Nothochrysa fulviceps*, *Nineta alpicola*, *N. vittata*, *N. flava*, and *Chrysotropia ciliata*

Table 1. Neuroptera collected in 2022–2023 by bait traps in the Mordovia Nature Reserve at the fire sites of 2021 (plots nos. 1–6) and 2010 (plots nos. 7–9), and areas not exposed to fires (plots nos. 10–11), number of individuals

	Species of Neuroptera	Plot number											2019–2023*	Total
		1	2	3	4	5	6	7	8	9	10	11		
	Chrysopidae													
1	*Apertochrysa prasina* Burm.	13/87	13/54	7/49	21/55	11/68	7/93	186/293	18/189	31/291	48/330	7/13	294	2178
2	*Chrysoperla carnea* Steph.	7/23	17/57	15/21	13/20	10/21	4/18	10/26	15/11	7/26	3/18	7/5	176	530
3	*Apertochrysa flavifrons* Br.	2/8	2/1	2/1	4/6	14/13	–/4	22/14	3/6	7/10	36/14	14/–	101	284
4	*Nineta alpicola* Kuw.	–/–	–/–	–/–	9/2	1/1	–/6	1/2	–/–	1/6	3/15	3/7	119	176
5	*Chrysotropia ciliata* Wesm.	–/–	–/–	–/–	–/–	–/–	–/1	–/1	–/–	–/2	1/1	–/1	156	163
6	*Apertochrysa ventralis* Curt.	–/6	–/3	1/1	5/9	3/8	1/18	8/17	–/3	–/30	1/29	–/1	17	161
7	***Chrysopa gibeauxi*** Leraut	–/1	–/–	–/–	–/8	–/1	–/2	–/17	–/–	–/2	–/–	–/1	6	38
8	***Chrysopa abbreviata*** Curt.	2/2	5/2	–/1	–/–	–/4	–/1	2/1	1/1	–/2	–/2	–/–	3	29
9	*Nineta vittata* Wesm.	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	21	21
10	*Cunctochrysa cosmia* Nav.	–/1	–/–	–/–	–/1	4/–	2/–	6/1	–/–	–/–	3/–	-/-	1	19
11	***Chrysopa perla*** L.	–/–	–/–	–/–	–/–	1/–	–/2	1/–	–/–	–/–	–/–	–/2	6	12
12	***Chrysopa walkeri*** McL.	–/–	1/1	–/–	–/–	1/3	–/–	–/–	1/–	–/–	–/–	1/–	1	9
13	*Cunctochrysa albolineata* Kill.	–/–	3/–	–/1	–/–	1/–	–/–	–/–	–/–	–/–	–/1	–/–	1	7
14	*Nothochrysa fulviceps* Steph.	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/1	–/–	–/–	5	6
15	*Nineta flava* Scop.	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/1	1/2	–/–	–/–	2	6
16	***Chrysopa commata*** Kis & Újh.	1/–	–/–	–/–	–/–	–/–	1/–	–/–	–/–	–/–	–/–	–/–	–	2
17	***Chrysopa dorsalis*** Burm.	–/–	–/–	–/–	–/–	–/–	–/–	1/–	–/–	–/–	–/–	–/–	1	2
18	***Chrysopa viridana*** Schn.	–/–	–/–	–/1	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–	1
	Hemerobiidae													
19	***Wesmaelius concinnus*** Steph.	–/–	–/–	–/–	–/–	–/–	1/–	–/–	–/–	–/–	–/–	–/–	1	2
20	***Hemerobius humulinus*** L.	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	1/–	–	1
21	***Hemerobius nitidulus*** F.	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	1	1
	Total number of individuals	25/128	41/118	25/75	52/101	46/119	16/145	237/372	38/211	47/372	95/410	33/30	912	3648
	Number of species	5/7	6/6	4/7	5/7	9/8	6/9	9/10	5/6	5/10	7/8	6/7	18	21

Neuroptera collected in 2022 are to the left of the diagonal line, collected in 2023 to the right. The species of Neuroptera that are obligate or facultative predators at the imaginal stage are highlighted in bold.

* The summarized data from Makarkin and Ruchin (2019, 2020, 2021, 2024b) on Neuroptera collected in 2019–2023 by CBT in forests and clearings of the Mordovia Nature Reserve that were not exposed to fires.

were not found there at all or were single (*Chrysopa gibeauxi*), while chortobionts represented by predatory species were found (*Chrysopa abbreviata*, *Ch. walkeri*, *Ch. commata*). Judging by the fact that predatory species are rarely attracted by these bait traps, their real numbers should be significantly greater than the figures presented in the Table 1. Phytophages and glycophages dominate here (*Apertochrysa prasina*, *A. flavifrons* and *Ch. carnea*), which readily attracted by the traps, can be found on shrubs and herbs, and on trees, so their presence is not surprising.

In plots nos. 4–6, some living trees remained after the fire of 2021, i.e., there is a greater diversity of vegetation. Accordingly, along with chortobionts, dendrobiotes appeared, such as *Nineta alpicola* (a total of 19 specimens), *Chrysopa gibeauxi* (11 specimens), and *Cunctochrysa cosmia* (7 specimens), but their numbers are small; the abundance of forest edge species *Apertochrysa ventralis* increased significantly (44 specimens versus 11 in nos. 1–3).

In late post-fire assemblages, 12–13 years after the 2010 fire, dendrobiots (*Nothochrysa fulviceps*, *Nineta alpicola*, *N. vittata*, *N. flava*, *Chrysotropia ciliata* and *Cunctochrysa cosmi*a) are still rare, although there are rare living trees in these areas (Fig. 1b). But this may be due to the traps being set low to the ground (at a height of 1.5 m); in forest areas that were not exposed to fires (plots nos. 10, 11), dendrobiotes are also relatively rarely attracted by these traps. Dendrobiots (especially *Chrysotropia ciliata* and *Nineta alpicola*) were caught significantly more often in traps which were located mainly in the canopies of trees in forests that were not exposed to fires (see Table 1, column “2019–2023”).

Big differences in the numbers of Neuroptera in 2022 and 2023 may be due to natural fluctuations, possibly related to weather conditions, rather than to environmental reasons, since these differences are present in both the late post-fire assemblages and in one of the non-burnt areas.

It has been previously shown that flying arthropods (both zoophagous and phytophagous), including lacewings, are among the most fire-tolerant groups (Moretti et al., 2006). Some flying insects may even benefit from ecological processes associated with landscape disturbances caused by fires (Steffan-Dewenter et al., 2002). The results of our studies confirm this. Chortobionts populate burnt areas the following year after a fire, i.e., those places that were previously inaccessible to them or where their numbers were low. Many lacewings generally prefer semi-open biotopes and forest edges, where there are herbs, shrubs, and rare trees; it is not without reason that species of the genus *Apertochrysa* Tjed. and *Chrysoperla carnea* dominate in gardens (Canard et al., 1979). For such species, post-fire landscapes are very favorable. This is also supported by the results of a study of post-fire neuropteran assemblages in the low and mid-mountain areas of the Swiss Alps, which were studied using interception traps (Duelli et al., 2019a, 2019b). There, after the fires, the numbers of of lacewing species that mainly prefer forest edges increased significantly, including *Apertochrysa prasisa* and *A. ventralis*. Oddly enough, not a single specimen of chortobiont chrysopids was collected there, although the traps were located close to the ground.

Moreover, fires can allow new species to enter the ecosystem (Pryke and Samways, 2012). One such species may be *Chrysopa viridana* Schneider, 1845 (Makarkin and Ruchin, 2024a). This species is rare in Russia and characteristic here of the forest-steppe in the Middle Volga Region and eastern Ukraine (Zakharchenko, 1979; Kovrigina, 1986). The only Mordovian specimen of the species was collected in plot no. 3, the landscape of which superficially resembles a steppe or forest-steppe (Fig. 1a). It could have penetrated this post-fire landscape from semi-open and open biotopes located to the south in Mordovia and called the “northern forest-steppe” (Yamashkin, 1998).

Fires are very unfavorable for dendrobionts (*Nothochrysa fulviceps*, *Nineta alpicola*, *N. vittata*, *N. flava*, *Chrysotropia ciliata* and *Cunctochrysa cosmia*); even 13 years after the fire, their numbers remain very low. It is characteristic that the hygrophilous dendrobiont *Chrysotropia ciliata* was found in the burned areas at best singly, more often it was absent altogether, although the species is common in the reserve in undisturbed forests. This species is even a co-dominant in unburned pine forests in Tatarstan (Makarkin et al., 2023). The same was noted in the Swiss Alps: this species was completely absent both in strongly burned areas and in areas where the fire was of moderate severity (Duelli et al., 2019a, 2019b).

CONCLUSIONS

It can be concluded thus that fires affect different groups of Neuroptera differently. Severe fires, which destroy almost all vegetation, are most favorable for chortobiont species (e.g. *Chrysopa abbreviata*, *Ch. walkeri*, *Ch. commata*) and species preferring forest edges (e.g. *Apertochrysa prasisa* and *A. ventrali*s), as a result of which their numbers increase. But such fires are very unfavorable for dendrobionts, especially such species as *Nineta alpicola*, *N. vittata* and *Chrysotropia ciliata*; these species may disappear in burned areas or are unable to restore their numbers for a very long time.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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