

SHORT COMMUNICATIONS

КРАТКИЕ СООБЩЕНИЯ

A NOTE ON POST-FIRE VEGETATION IN PINE FORESTS OF THE MORDOVIA STATE NATURE RESERVE, RUSSIA

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Wildfires pose dramatic and devastating effects on natural habitats around the world, being important determinants of environmental transformation. At present, pyrogenic successional patterns and forest structure remains quite unknown in damaged ecosystems. This paper was aimed to evaluate the plant abundance in pine (*Pinus sylvestris*) forests at various burning treatments in the Mordovia State Nature Reserve, European Russia. In 2021–2023, the sampling was performed on 11 permanent plots, including two unburned, three once-burned (in 2010 only), and six twice-burned (in 2010 and 2021) sites. On 11 plots, 36 vascular plant species from 32 genera and 21 families have been registered in total. Expectedly, the results demonstrated significant ($p < 0.05$) differences between once- and twice-burned plots based on the plant abundance in both ground and shrub-sapling layers, which can also be explained by differences in the time of the post-fire regeneration of the forest ecosystem. Based on plant abundance in the ground layer of burned sites, significant ($\chi^2 = 11.880$, $p < 0.01$) differences were found between the studied years. Significant differences in plant abundance on burned plots were found between 2021 and 2023 ($p < 0.01$), and 2022 and 2023 ($p < 0.05$). At the same time, no differences ($\chi^2 = 3.816$, $p = 0.148$) were found between the studied years based on plant abundance in the shrub-sapling layer on burned plots. The obtained results confirm the main patterns of post-fire re-vegetation in forest communities, but require additional studies to make stronger conclusions.

Key words: burned area, percentage cover, *Pinus sylvestris*, Protected Area, pyrogenic succession

Introduction

Wildfires are recognised as one of the most considerable natural disasters of forest ecosystems, and hundreds of thousands of them occur annually around the world (Yue et al., 2020). Their impacts on ecosystems, biodiversity, carbon reserves, and climate are often overlooked (Bowman et al., 2009). Some authors (e.g. Kharuk et al., 2021) found a significant increase in the annual burned area of Eurasian forests over the 2000s. In particular, the annual burning rate of Russian forests was estimated at about 570 000 km² (Bartalev et al., 2015; Kharuk et al., 2021). Wildfires are one of the key factors, impacting the dynamics of forest vegetation (Atutova, 2023), and forest-dwelling species (Tiberio et al., 2022; Vasilyev et al., 2023).

The effects of wildfires on vegetation and soil are closely attributed to wildfire characteristics, such as its density, frequency, severity, intensity (e.g. Morgan et al., 2001; Whitman et al., 2019; Kharuk et al., 2021). All these components of wildfires impact the conditions of the regenerated vegetation. This study was aimed to estimate the plant abundance in *Pinus sylvestris* L. (hereinafter – pine) forests at various fire-

frequency and reforestation time treatments in the Mordovia State Nature Reserve (Russia). We hypothesised that i) the abundance of vascular plants does not differ between forest sites, once- and twice-damaged by wildfire, and ii) differences in plant abundance are more pronounced in ground layer than in the shrub-sapling layer on fire-damaged sites.

Material and Methods

The study area includes pine forests in the Mordovia State Nature Reserve, in the centre of European Russia (54.773° N, 43.191° E). Forest communities cover 96% of the total territory of the Protected Area, of which 50% are pine forests. In 2010, about 46% of the Protected Area was damaged by a wildfire (Kharitonova & Kharitonova, 2021), which affected post-fire succession in various forest types (Khapugin et al., 2016). In 2021, a new wildfire event occurred in the Mordovia State Nature Reserve. It was damaged about 120 km² of the Protected Area, including territories fire-damaged in 2010. This wildfire event has destroyed young saplings of trees and ground layer in young 10-year-old forest communities.

Vegetation surveys were performed on 11 permanent 10×10-m plots in August 2021–2023 (Table 1). In each of them, we studied the abundance (considered here as a percentage cover) of vascular plants in the tree (if any), shrub-sapling, and ground (considered here as the sum of herbs, dwarf semi-shrubs, and ferns) layer. A list of all sampled vascular plant species is available in Electronic Supplement 1. Plant species names follow the POWO (2024) database.

All study plots were divided into control (unburned), once-burned (in 2010), and twice-burned (in 2010 and 2021) plots (Table 1). We tested, whether the fire frequency determines differences in vascular plant abundance on the study plots. The main limitation was the lack of data about the plant abundance on sites, burned just in 2010. Thus, we studied the partially renewed forest communities on once-burned sites and twice-burned sites, where the reforestation processes had just started in 2021.

For analysis, we used combined abundance values per layer of the forest community. Differences in plant species abundance between the three studied years were assessed using Kruskal-Wallis tests. Paired Mann-Whitney tests were carried out to detect differences between plant species abundance in certain years. Since we expected no changes in the plant species abundance on unburned sites, we conducted analyses both with and without the inclusion of data from unburned (control) plots.

We used Non-metric multidimensional scaling (NMDS, Bray-Curtis similarity) to group plots according to the combined species abundance, and one-way PERMANOVA (Bray-Curtis dissimilarity, Anderson, 2001) to assess differences between distinguished groups of fire-damaged plots. Since the tree layer was present only on unburned (control) sites, only shrub-sapling and ground layers were included in the analyses of plot groups. All analyses were performed using PAST 4.16 (Hammer et al., 2001).

Table 1. Characteristics of the study plots established in the Mordovia State Nature Reserve, Russia

Plot	Burning treatment	Latitude	Longitude	Wildfire event year(s)
Plot1	Once-burned	54.7824	43.1754	2010
Plot2	Once-burned	54.7822	43.1828	2010
Plot3	Twice-burned	54.7823	43.1835	2010, 2021
Plot4	Twice-burned	54.7831	43.2002	2010, 2021
Plot5	Twice-burned	54.7840	43.2157	2010, 2021
Plot6	Twice-burned	54.7807	43.2208	2010, 2021
Plot7	Twice-burned	54.7655	43.2185	2010, 2021
Plot8	Once-burned	54.7646	43.2183	2010
Plot9	Twice-burned	54.7730	43.2354	2010, 2021
Plot10	Unburned, control	54.7723	43.2357	–
Plot11	Unburned, control	54.7685	43.2368	–

Results

In total, we found 36 vascular plant species belonging to 32 genera and 21 families (Electronic Supplement 1). They consist of 24 herbs, two ferns, six shrubs, and four trees. In the ground layer of the burned plots, *Calamagrostis epigejos* (L.) Roth, *Pteridium pinetorum* C.N.Page & R.R.Mill, *Erigeron canadensis* L., and *Epilobium angustifolium* L. had the highest abundance over the studied period. In the shrub-sapling layer, *Betula pendula* Roth, *Pinus sylvestris*, *Chamaecytisus ruthenicus* (Fisch. ex Wolf.) Klásk., and *Populus tremula* L. demonstrated the highest abundance.

Plant species abundance based on selected determinants

Non-metric multidimensional scaling allowed us to test the identity relevance of three groups based on fire frequency (Fig. 1A, B). One-way PERMANOVA indicated that these three groups were significantly different in plant species abundance in both ground and shrub-sapling layer ($F = 3.359$, $p = 0.0118$, and $F = 4.273$, $p = 0.0006$, respectively). But the pairwise PERMANOVA analysis shown significant difference only between once- and twice-burned sites ($p = 0.0359$) in the shrub-sapling layer and between twice-burned and unburned sites ($p = 0.0108$) in the ground layer. This coincides with Fig. 1A, where for the ground layer dots of unburned and once-burned sites are closely located, while in the shrub-sapling layer (Fig.1B), dots of unburned sites are located between dots of once- and twice-burned sites.

Annual changes in the plant species abundance

Kruskal-Wallis analysis showed significant differences in plant species abundance of the ground layer between the studied years for all 11 plots ($\chi^2 = 9.061$, $p = 0.011$) as well as for all nine burned plots ($\chi^2 = 11.880$, $p = 0.003$). Taking into account only burned plots using Mann-Whitney tests, the plant abundance differed significantly between 2021 and 2023 ($p < 0.01$), and between 2022 and 2023 ($p < 0.05$), while for all studied plots the changes in plant species abundance significantly differed only between 2021 and 2023 ($p < 0.01$).

In the shrub-sapling layer on all 11 sites, we did not find any difference in plant species abundance between the distinguished groups. However, in this case, the Mann-Whitney test showed significant differences between 2021 and 2023 ($p = 0.045$). If we consider only burned sites, there were no differences in plant abundance either ($\chi^2 = 3.816$, $p = 0.148$).

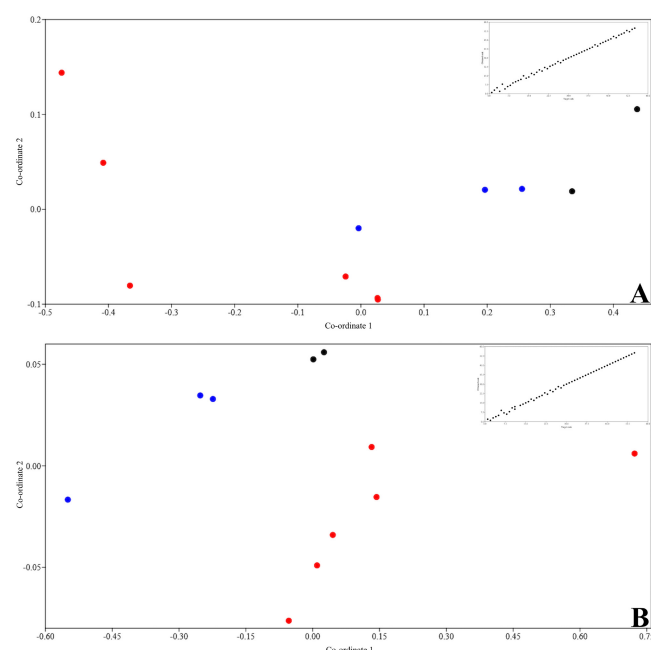


Fig. 1. Non-metric multidimensional scaling (Bray-Curtis dissimilarity) between species abundance data, showing the fire-frequency groups of studied plots in the Mordovia State Nature Reserve, Russia. Shepard plots are placed in the upper right corner of each subplot. Designations: A – ground layer, B – shrub-sapling layer; red dots – twice-burned plots, blue dots – once-burned plots, black dots – unburned plots.

Discussion

The study has shown that the plant abundance of ground and shrub-sapling layers differs between once- and twice-burned sites. This does not coincide with our first hypothesis. We expected a quite similar plant abundance on once- and twice-burned plots by 2023 since no changes in environmental conditions of pine forests during five post-fire years in the same area was found earlier in the Mordovia State Nature Reserve (Khapugin et al., 2016). Our results are also in agreement with other studies, which reported a negative impact of repeated fires on the reforestation process in various forest ecosystems (e.g. Stevens-Rumann & Morgan, 2016; Shvetsov et al., 2019). However, we must take into account an important limitation of this research, namely the lack of data on plant abundance on once-burned sites. Therefore, the found differences can be explained rather by a different stage of reforestation processes on once- and twice-burned plots.

Based on our results, 13-year pyrogenic once-burned sites tend to be at the intermediate position between undisturbed (control) and twice-burned forests. At the same time, in agreement with our second hypothesis, differences between once-, twice-burned, and

unburned plots were much smaller for shrub-sapling layers. This is not completely coinciding with other data suggesting that the repeated fires reduce the regeneration of shrubs and tree saplings (e.g. Shvetsov et al., 2019; Whitman et al., 2019; Smith-Ramírez et al., 2021), with a certain increase in abundance of herbaceous plants (e.g. Vilà-Cabrera et al., 2008). However, all the mentioned research results have been obtained far from the present study area, due to the lack of similar comparable data from (sub) boreal forest in the centre of European Russia. Hence, additional information is needed to make stronger conclusions.

The obtained results may be useful for other research regarding biota. Many animal species use forest communities, as a home range (e.g. Duco et al., 2024; Ogurtsov et al., 2024) or feeding sources (Vasilyev et al., 2023; Ogurtsov et al., 2024). The research of various animal groups in ecosystems at different stages of the post-fire reforestation process can provide a comprehensive understanding of ecosystem regeneration after wildfire impact.

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Supporting Information

Additional data for the paper may be found in the [Supporting Information](#).

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СООБЩЕНИЕ О ПОСЛЕПОЖАРНОЙ РАСТИТЕЛЬНОСТИ В СОСНОВЫХ ЛЕСАХ МОРДОВСКОГО ГОСУДАРСТВЕННОГО ПРИРОДНОГО ЗАПОВЕДНИКА (РОССИЯ)

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Лесные пожары оказывают серьезное разрушительное воздействие на природные местообитания в разных регионах мира, являясь важными детерминантами трансформации окружающей среды. В настоящее время существует определенный недостаток данных о процессах пирогенных сукцессий и формировании структуры лесных сообществ в поврежденных пожарами экосистемах. Целью данной работы была оценка обилия растений в сосновых (*Pinus sylvestris*) лесах в разных условиях послепожарного восстановления в Мордовском государственном заповеднике (Европейская Россия). Исследование было проведено в 2021–2023 гг. на 11 пробных площадях, в т.ч. на двух негоревших, трех однократно горевших (только в 2010 г.) и шести дважды подвергнувшихся пожару (в 2010 и 2021 гг.) пробных площадях. На 11 пробных площадях было зарегистрировано в общей сложности 36 видов сосудистых растений из 32 родов и 21 семейства. Ожидаемо, результаты показали значимые ($p < 0.05$) различия в обилии растений между однократно и двукратно горевшими участками как в травяно-кустарничковом, так и в кустарниковом ярусах. Это может быть объяснено различным временем, прошедшим с момента пожара. Выявлены значимые ($\chi^2 = 11.880$, $p < 0.01$) различия в обилии растений между годами исследования в травяно-кустарничковом ярусе горевших площадей. Значимые различия в обилии растений на горевших площадях выявлены между 2021 и 2023 гг. ($p < 0.01$) и между 2022 и 2023 гг. ($p < 0.05$). В то же время не было выявлено различий в обилии растений в кустарниковом ярусе между исследуемыми годами ($\chi^2 = 3.816$, $p = 0.148$). Полученные данные соотносятся с основными закономерностями послепожарного восстановления растительности в лесных сообществах, но требуют дополнительных исследований для более убедительных выводов.

Ключевые слова: *Pinus sylvestris*, гарь, особо охраняемая природная территория, пирогенная сукцессия, проективное покрытие