Post-fire succession in scots pine forests of southern taiga central Siberia

V A Ivanov¹, G A Ivanova² and N M Kovaleva²

¹ Reshetnev Siberian State University of Science and Technology, 31 Krasnoyarsky Rabochy Av., Krasnoyarsk, 660037, Russia
² Sukachev Institute of Forest, Siberian Branch, Russian Academy of Sciences, Krasnoyarsk, Russia

E-mail: ivanovv53@yandex.ru

Abstract. Fire is one of the main disturbance factors in the boreal forests of Russia. Forests dominated by Scots pine (*Pinus sylvestris* L.) are widespread in Central Siberia, with large areas burned annually. We studied post fire succession of ground vegetation following experimental fires of various intensities on typical Scots pine forest sites. The greatest changes in ground vegetation and biomass of these pine forests were after fires of high intensity. After fires of low intensity ecosystem components recovered rather quickly to pre-fire composition. These results are important for determining the effects of fire behavior and intensity on rates and patterns of post-fire vegetation recovery in southern taiga Scots pine forests of Siberia.

1. Introduction

Forest fires can have a long-lasting and substantial influence on successional dynamics of boreal forests. Being an important evolutionary and ecological factor, wildfires influence forest structure and composition, affect surface vegetation and animal habitat, and regulate a wide range of ecosystem processes [13, 15].

Fire impact on vegetation shows itself variously both as a result of a direct influence on plant communities during wildfires and indirectly - through pyrogenic (post-fire) succession. The post-fire succession of a plant community depends on many factors: physical-geographical conditions, climate, and pre-fire structure of plant community [3, 7, 12].

Ecological heterogeneity of vegetation in the subcanopy and surface vegetation, which is often barely visible from above the tree canopy, is strongly evident in post-fire succession. The resulting partial or complete changes in surface vegetation can lead to diverse pathways of post-fire vegetation regrowth and recovery. Forest fires facilitate invasion of early successional species, although often the post-fire community is dominated by species that have survived the fire [18].

Forest fires change not only species diversity of surface vegetation within habitats but also diversity of ecotopes themselves. The nature of post-fire successions is determined by fire intensity [11, 16]. Fire intensity influences germination and amount of viable seeds in soil and also soil nutrients on which the post-fire vegetation succession depends [8]. Increased fire intensity impacted on species composition, percent cover and biomass of ground vegetation [5]. The post-fire regeneration of vegetation results in biomass accumulation. The accumulation of post-fire biomass can be impacted by many factors such as forest type, age, tree stand density and so on, as well as the type and intensity of a fire [6].
Pine forests of Central Siberia are exposed to fires of widely varying intensity dependent on fuel loads, fuel condition, and the weather conditions before and during the fire. As a result these forests contain a complicated landscape matrix of stands at different stages of post-fire regeneration [1]. The fire impact in one case may be limited to partial destruction of the lower vegetation layers or partial damage of a tree stand, in another case the fire may cause high levels of understory fuel consumption and canopy mortality, killing almost all living vegetation of the pre-fire plant communities. Fire impact on plant communities should be considered in respect to their structural elements: ground vegetation (shrubs, herbs, moss, and lichen), understory, tree regeneration and the overstory tree stand.

The objective of this paper is to describe changes in forest floor vegetation and above ground biomass in southern taiga pine stands of Central Siberia after surface fires of various intensities.

2. Materials and methods

Studies were carried out in pine stands, which are representative for Central Siberian Scots pine-dominated forests. Experimental plots (4 ha each) were set in the Angara river basin in Govorkovo (Plots 1, 2) (58º35'N, 98º55'E) and Khrebtovo (Plots 3, 4) (58º42'N, 98º25'E). Soils were alluvial-ferriferous podzols on experimental plots.

Plots 1 and 2 were in dry Scots pine forest with lichen and green moss in ground vegetation. This stand was on a flat step of a slope, and had last been burned in 1922, more than 80 years before experimental fires. The average tree age was 90 years. Species Vaccinium vitis-idaea, Pleurozium schreberi and Cladonia rangiferina dominated in the ground vegetation. Plots 3 and 4 were in a more mesic Scots pine forest where dominated herbs and green moss in ground layer. This stand occupied a gentle slope, last burned in a surface fire in 1948, more than 50 years before our experimental fires. The average tree age was 100–120 years. Understory (Alnus sp.) forms the layer height up to 3.5 m on the average. Species Vaccinium vitis-idaea, Linnaea borealis L., Maianthemum bifolium L. F. W. Schmidt, Iris rathenica Ker-Gswl, Pleurozium schreberi dominated in ground vegetation.

In 2002, 2003 years were conducted prescribed fires to characterizing and modeling the fire behavior and ecosystem effects of fire burned under different weather on a series of plots in central and southern taiga stands [4, 10]. During these experiments we conducted prescribed fires to simulate the behavior of natural surface fires, which are typical for the Scots pine stands of Central Siberia. According to the intensity classification of forest fires [10] a high intensity of fire was on experimental plot 2 (4876 kW/m), moderate intensity – on the plot 1 (3195 kW/m), low intensity of fire – on plots 3 and 4 (878 and 924 kW/m).

To estimate the structure and biomass of forest floor vegetation, litter and duff the methods developed by D. J. McRae [9] were used on these experimental plots. The samples of living ground vegetation, litter and duff were collected before fire and every year after fire to monitor biomass. The biomass of down woody debris was estimated by the line-intersect approach [9, 19]. The tree stand biomass was assessed by inventory methods and by harvesting model trees by diameter classes. Based on obtained data on biomass of model trees and on distribution of trees by diameter classes the biomass of living trees and dead standing trees was calculated for the experimental plots.

Species diversity and percent cover were measured on 25 (1m x 1m) sub-plots on every plot before and after experimental fires [17]. Structure of ground vegetation was mapped on plots before and after fires (1, 3, 7, 13 years). The plant microgroup was the main mapped unit [14]. Schematic maps of vegetation were developed using the ESRI ArcMap program.

3. Results and discussions

We compared the initial stage of post-fire succession in southern taiga pine forests after fires of different intensity. Natural tree mortality in these forests stands before fire was from 2 to 15% of the total tree number. The main post-fire tree mortality – up to 90% from the total tree number died during 13 years occurred in the first two to three years after fires. By thirteen years past the high intensity of fire (Plot 2) the tree mortality was 71.1% and after fires of moderate and low intensity 18.3 (Plot 1) and 9.8% (Plot 3), 6.4% (Plots 4) of the total number of trees, respectively (table 1). On our obtained data for experimental plots in southern taiga and our earlier data about experimental fires in central
taiga Scots pine forests [4, 6], the tree mortality correlate with fire line intensity, the correlation coefficient characterizing this relationship is 0.83 (figure 1).

Table 1. Dynamics of the tree mortality in pine forests after fires of different intensity (% of the number of trees before the fire)

| Fire intensity | Plot | Time after fire, year |
|----------------|------|-----------------------|
|                |      | 1        | 2     | 3     | 4     | 5     | 8     | 13    |
| Low            | 3    | 3.3      | 5.4   | 5.4   | 7.6   | 8.7   | 9.8   | 9.8   |
|                | 4    | 3.2      | 4.2   | 6.4   | 6.4   | 6.4   | 6.4   | 6.4   |
| Moderate       | 1    | 11.8     | 16.1  | 16.1  | 16.1  | 17.2  | 18.3  |       |
| High           | 2    | 61.8     | 70.1  | 70.1  | 70.1  | 71.1  | 71.1  |       |

Regardless of fire intensity the highest mortality occurred in trees of smaller diameters. The relation of mortality with tree diameters was strong ($r = 0.88; p < 0.05$). A study of causes of mortality on our earlier set of prescribed fires in central taiga Scots pine forests showed that mortality was significantly related to char height and degree of colonization of a tree by bark insects after the fires respectively. Fires of high intensity stimulated weakening of trees and increased tree colonization by insects [2].

![Figure 1. Relationship between tree mortality and fire line intensity in pine stands of Siberia](image)

We analyzed species composition of ground layer before and after experimental fires. Pre- fire vegetation pine stand (Plots 1, 2) had low species diversity: shrubs and herbs (11 species), green mosses (3 species) and lichens (7 species). Plots 3 and 4 had great abundance of shrubs and grass (20 species) and moss-lichen layer (6 species).

The number of species increased up to 16 species (Plots 1 and 2) and up to 24 species (Plots 3 and 4) after experimental fires. All the species pre-fire also remained in the years following the fires. Such species as Calamagrostis epigeios (L.) Roth, Chamaenerion angustifolium L., Rubus saxatilis L. appeared in ground layer after fires of moderate and high intensity (Plots 1 and 2). Species Hieracium umbellatum L. and Chelidonium majus L. appeared in ground layer after the low intensity of fire (Plot 4) (figure 2).

Percent cover of herbs and shrubs decreased after fires but the cover of ground layer increased with time since fires. Regeneration of herbs and shrubs proceeds by vegetative reproduction of surviving plants or their seeds. The percent cover of the dominant shrub Vaccinium vitis-idaea reached its pre fire levels in during 7–8 years.

The percent cover of moss layer decreased after fires depending on intensity. Lichen layer burned completely in fires of moderate and high intensity. Scattered lichen patches (< 1% percent cover)
remained among mosses in unburned areas on the plots after low intensity fires (Plot 4). Sites where forest floor burned to the mineral layer was colonized by mosses (*Polytrichum commune* Hedw., *P. strictum* Brid.), which reached about 10% cover by the 13 year after fires of moderate and high intensity. Percent cover of pre-fire mosses (*Pleurozium schreberi, Dicranum polysetum*) was only 1–10% by 13 years post fire (before fire – 30–80%).

After experimental fires the herbs and shrubs dominated the plant community on all plots, independent of fire intensity. *Vaccinium vitis-idaea* microgroup dominated in the ground vegetation five years after the prescribed fires (figure 2). Initial species such as *Calamagrostis arundinacea* (L.) Roth, *Chamerion angustifolium* and *Polytrichum* dominated in sites with the greatest depth of burn in the litter and humus layers. However, in sites with the lowest depth of burn the role of such herbs as *Maianthemum bifolium, Lycopodium clavatum* L intensified. After fire of low intensity regeneration of pre-fire mosses (*Pleurozium schreberi, Dicranum polysetum*) led to expanded cover of these species in the microgroup (*Vaccinium vitis-idaea–Pleurozium schreberi*) relative to before fire.

**Figure 2.** Structure of plant microgroups before and after the experimental fires of a) high (Plot 2), b) moderate (Plot 1), c) low intensity (Plot 3).

Biomass of forest ecosystems is the fuels that support wildfire spread. It is extremely rare for this biomass to burn completely. We evaluated the effects of fire on major components of the Scots pine ecosystems studied here. These components include the trees, tree regeneration, understory, and ground soil vegetation. These different components of the forest ecosystem contribute differently to available fuels in a fire and experience different impacts from fires as well. The amount of burned biomass is determined by the intensity of the fire. Mosses and lichens were fully destroyed by fire. All fires resulted in reduction of biomass lichen, moss, herb, small bushes, small branches and windfall. On all plots fire resulted in death of all young tree regeneration.
Over the years, dead organic matter accumulates at all sites after fires as a result of the cast of needles, bark and branches from trees damaged by fire and the fall of deadwood trunks. By 13 years post fire the biomass of living trees in the pine forests on plot 1–4 decreased 16–62% by five years post fire depending on fire intensity.

Accumulation of above ground biomass after fires in these southern taiga pine forests greatly depended on burn intensity. After fires the live biomass killed but not consumed in the fire is re-distributed to mort mass.

At the same time forest floor vegetation gradually increased after fire. Fire intensity affected depth of burn of forest litter, which undoubtedly had an effect on the success of seedling regeneration. By 13 years post fire the number of seedlings after the moderate intensity fire in pine forest with lichen and green mosses (Plot 1) reached 68 thousand per ha.

Total above ground biomass on experimental plots changed slightly after fires of low and moderate intensity. A greater initial decrease of living ground vegetation and duff loads is typical after moderate intensity fires due to higher fuel consumption and tree mortality. Living biomass decreased an average of 10% after the low intensity fires by 15% after the moderate fire intensity. The greatest changes in the structure of aboveground organic matter distribution were after the high intensity fire, when the aboveground living biomass decreased by 85% (figure 3).

Biomass of species Vaccinium vitis-idaea also increased after fires on all plots. By four to six years after high intensity fire biomass of Calamagrostis arundinacea increased up to 24% (compared to 3% before fire). Lichens were not regenerated in the first eight to nine years after fires. Biomass of mosses was less than 1% of the pre fire value 13 years after fires of high and moderate intensity. Fires of low intensity resulted in reduction of moss biomass by 68% (1 year after the fire). In the following post-fire years forest floor biomass gradually increased.

![Figure 3](image)

**Figure 3.** Forest above-ground biomass dynamics in southern taiga lichen pine stands following fires of high intensity (Plot 2). The living biomass includes the tree stand, regeneration, lichen-moss and grass-small shrub layers; dead biomass consists of dead standing trees, down woody debris, litter and duff.

**4. Conclusions**

Post fire ground vegetation at the initial stage of fire succession depends on a complex of factors (fire intensity, depth of duff consumption, and pre-fire forest type). In the course of studies the experimental data on impact of different intensity fires on dynamics of the above ground biomass of southern taiga pine forests of Central Siberia were obtained.

Fires, regardless of their intensity, decreased percent cover and biomass of ground vegetation. The greatest changes in ground layer were in pine forests with dominated lichen and green moss after fires of high and moderate intensity. In these situations where most or all of the lichen-green moss cover
was burned, *Vaccinium vitis-idaea* recovered fairly rapidly, but there was also considerable invasion of grass and herbaceous species that had been largely absent pre fire.

The post-fire accumulation of biomass was strongly related to fire intensity. In the first several years after fire the increase of dead biomass correlates well with fire intensity. Later in succession, the impact of fire intensity on vegetation recovery and on dead biomass accumulation decreases. After fires the dead biomass continues to accumulate, especially following high intensity fires, as dead branches and standing dead tree fall to the forest floor. The high intensity fire leads to high levels of dead biomass, which becomes an increasing proportion of the total biomass.

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