The impact of fires on the landscapes of the Baikal-Dzhugdzhur type under climate fluctuations

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Abstract. In light coniferous forests of the Baikal-Dzhugdzhur type fires are considered as factors and processes inseparable from the forest landscapes and their dynamics. The study period of 1998–2015 is highlighted as extremely arid. In 2008, 2013–2014, 2018 conducted ground studies of the state of vegetation after fires in the area of Vitim Plateau. The conditions of arid period with high frequency, duration and intensity of fires were the main factors in the dynamics of transformation of the structure of mountain-taiga larch forests. Analysis of cruising materials and expedition research showed that from 1996 to 2015 the area of larch forests with canopy density of 5–7% decreased by 45–50%. The area of burned forests and thin forests increased by 45–48%, and the area of shrubs – by 17.0%. The main part of forests is disturbed at the foot of the mountains and in intermountain depressions, at altitudes of 942–1100 m. Strong desiccation of the ground cover and consistent ground fires with complete loss of trees and undergrowth activated natural processes of bush formation and prairiefication. The duration and degree of fluctuations in climatic parameters determine the nature of the impact of fires on Baikal-Dzhugdzhur larch forests and the degree of their transformation.

1. Introduction

General features of the mountain-taiga Baikal-Dzhugdzhur geosystems are associated with the geophysical conditions of Late Cenozoic era i.e. with the Quaternary period of cold winters, development of permafrost, very high seasonal temperature amplitudes and mid-mountain relief [1]. These parameters are landscape-forming for the study area and for the territory of the region in general, as the mountain-depression relief and the influence of the Siberian anticyclone preserve their relevance. Modern climatic parameters to a greater extent reflect the features of sharply continental climate. High elevation of relief (altitudes 960–1450 m) and strong radiative cooling in winter determine lower annual temperatures, and temperatures of the vegetation period in comparison with other territories located at similar latitudes. The average annual air temperature is -3.3°C and the sum of temperatures above 10°C ranges from 920° to 1530° [2]. The duration of the frost-free period is 67-69 days, and the duration of the vegetation period is 150–155 days. The annual amplitude of average monthly air temperatures fluctuations reaches 42°, and absolute temperature fluctuations reach 86°. Severe winters with little snow cause the spread of different types of permafrost, which thickness within the Beklemishevskaia depression reaches 100–110 m [3]. Of particular importance here are the gently sloping landforms and soils developed on rocks with reduced water permeability, medium and heavy loams, which preserve permafrost within the soil profile throughout the year. Negative average annual temperatures across the entire soil profile are recorded here (−4−1°C) [4].
The complex of forest and vegetation conditions of the area has left a mark on the formation of a peculiar cryoxerophytic flora and vegetation, the main part of which is covered by low quality larch forests of Gmelin larch – *Larix gmelinii* (Rupr.) and dwarf arctic birch with *Betula fruticosa* Pallas. s.l. Low quality trees and openness of larch canopies causes low density of the tree cover. The illumination under the tree cover with the density of 0.3-0.6 is 2–3 times higher than under a canopy of larch forests of taiga zone with the same density [5]. Shrubs and herbaceous plants develop intensively under the clear-boled forest canopy. The degree of grass and shrub cover vary from 60 to 100%. Annually dying off ground phytomass of herbaceous plants in light coniferous forests is a very significant element of combustible material in locations where the spring and early summer are characterized by extreme dryness.

Permafrost not only corrects the development of grass and shrub cover, which is combustible material, but also dampens it during thawing. The following types are distinguished in Zabaykalye: slope-submountain, permafrost-depression, permafrost-barrier, and glacial overwetting types [6]. The relief forms and soils developed on rocks with low permeability, medium and heavy loams are of particular importance. Under the influence of climatic changes, permafrost water saturation and the moisture content of combustible materials from suprapermafrost water are significantly altered. During the last 59 years, precipitation in the Ivano-Arakhleysky lakes area ranged from 149.8 to 551.4 mm a year with the average value of 308.6 mm. The decades (1961–1970 and 1971–1980) were more humid, the last two decades (1991–2000 and 2001–2015) were characterized by the driest conditions [7].

According to the long-term data, periodicity of spring and early summer droughts is 2–4 years. With such periodicity there are no deep changes in the process of ground cover moistening and fires are rare. Our study period from 1998 to 2015 was characterized by spring-summer temperatures exceeding average annual norms, absence of precipitation in late summer and autumn and 13 years of drought.

The relevance of the research is related to the fact that during the study period Baikal-Dzhugdzhur larch forests were referred to areas with the highest fires frequency [8–10].

In 2003–2018 field studies were conducted to assess the condition of mountain taiga landscapes in the south of the Vitim Plateau.

The purpose of the present research is to obtain current data on the state of vegetation, which may be indicators of changes in the natural conditions of the Baikal-Dzhugdzhur landscapes under the impact of fires under climate fluctuations.

The object of the study is vegetation of the Baikal-Dzhugdzhur type landscapes.

2. Data and Methods

We used the method of sample plots located in different forest site types and affected by fires of different form and strength, and plantations which were not affected by fires. The plots were established and described in accordance with the generally accepted methods [11–14]. Grass cover characteristics were given for the whole sample area with indication of species composition and coverage in %. Biodiversity was evaluated according to the index of concentration of the abundance of species and the index of rare species. To obtain quantitative characteristics, 1996 forest inventory materials, field survey materials, and published satellite data were used. The study area belongs to the Vitinskaya taiga-plain province of the Baikal-Dzhugdzhur mountain-taiga region.

The sample areas are located in the Beklemishevo basin and the slopes of the adjacent mountain ranges: the Osinovy Mountain Range to the north-west and the Yablonovy Mountain Range to the south-east figure 1.
Mountain-and-hollow relief determines circular combination of natural complexes. Small and large lakes in the central part of the basin are framed by cryoarid meadow-shrub, swamp-shrub, shrub-forest communities, which rise along the river valleys and intermountain depressions on the slopes of ridges, where they more or less border with mountain taiga larch forests of various types.

Flat-topped watershed areas of the Yablonovy and Osinovy ranges at the absolute altitudes of 1100–1445 m are represented by mountain taiga larch forests of limited development of indigenous type with mixed undergrowth with predominance of dwarf birch. Slope landscapes are the most diverse by their characteristics, which is associated with the forms of relief and different exposure of the range slopes. Foothill and submountain areas at the altitudes of 1066–1200 m have a hilly appearance. Foothill depressions are characterized by permafrost heaving and bogginess of the valley bottoms. These areas are occupied by sparse larch forests, dwarf birch, shrubby meadows. In the foothills, forb larch forests and birch-larch grass forests with shrubby undergrowth are widespread, in some places steppificated. In the foothill and intermountain depressions, at an altitude of 942–1060 m, various combinations of taiga, dwarf birch, meadow, and meadow-bog communities are noted [15].

According to the cruising data of 1996, the area of low-density larch forests prevailed in the study area (figure 2).
The average composition of plantations is characterized by the formula 10L, 8L2B, 5B3L1C1Os, 10Er+Os, which make up: larch 60–70%, dwarf birch 13–16%, birch 12–15% of the forested area. Pine and aspen forests constitute from 0.7 to 0.2% of the forested area, as the forest growth conditions for their development are limited.

On the basis of route descriptions of sample areas "Osinovka" and "Ryshmaley" 7 forest types were identified: ledum, sedge, dwarf birth, alder, rhododendron with predominance of forb and vaccinum forest types.

In the age structure of forests, according to the 1996 inventory, the areas of mature and overmature forests prevailed. Mature plantations, especially of dwarf birch type, fell into the category of increased risk during the study period.

3. Results and discussion
The main factor of change in the state of mountain taiga larch forests during the dry period is the frequency and intensity of fires. Analysis of our findings showed that from 1996 to 2015 the area of larch forests with the density of 5–7% reduced by 45–50%. The area of burned areas and thin forest increased by 45-48%, and the area of shrubs by 17.0%.

The loss from the inventory of mature larch trees after severe ground fires ranged from 40 to 100%, depending on the type of forest. The increased damage of mature trees by fires is associated with better drying of the soil cover, its stronger burning (often to the mineral layer of soil), damage of the larch roots and mass falling of trees under strong winds.

Reforestation on burned areas lasts for 15–20 years and more. Undergrowth of wood species includes larch, birch, aspen and, rarely, pine. Larch undergrowth dominates in forests that have not burned for a long time, while birch and aspen undergrowth predominate in fire damaged and burned areas.

In general, regeneration on 70% of the areas of fire damaged and burned areas is difficult and occurs through change of species or transformation into shrub communities.

The impact of fire has different consequences for dwarf birch communities. Single and short-term fires do not have a significant destructive effect on dwarf birch [16–17]. This is due to the fact that dwarf birch has a form of a geoxilic vegetatively immobile shrub (according to the classification of I. G. Serebryakov [18]), its dormant regeneration buds are underground and are usually not damaged by fire. Moreover, after burning, the areas devoid of herbaceous vegetation become the main micro-

![Figure 2. Area ratio in the sample areas with various density stands and dwarf birch.](image-url)
ecotopes for germination of its small seeds, which contributes to rejuvenation of the population. The surviving single trees and groups of larch cannot compete with the thickets of dwarf birch, which has a high seed and coppice reproduction capacity.

Persistent and repeated heavy ground fires damage regeneration buds and some of the dwarf birches die. This changes hydrothermal regime of soils and intensifies permafrost thawing, which leads to prairification and bogging in the lowlands, and to steppification on the uplands. Dwarf birch communities are often located in complex with shrubby meadows, which turn into marshy and steppe meadows. The assessment of biodiversity dynamics, based on geobotanical analysis of descriptions from 97 sample plots showed decrease of vegetation species number in areas exposed to fires. The number of plant species at the burned areas is (20–23), in non-burned forests (25–27). Steppificated meadows are the most diverse by floristic composition (29–32 species) among the researched plant communities.

The prolonged dry period intensified the development of steppe group species, the number of which significantly increased in all plant communities.

According to our data Species Abundance Concentration Index in perennial stands, which were not affected by fires for a long time 15.9; in areas affected by weak fires 7.1; in areas affected by heavy fires 6.0; in shrubs 7.2; in the meadows 10.

4. Conclusion
Against the background of the recorded global warming trend, forest ecosystems of the Baikal-Dzhugdzhur type became more vulnerable, which is associated with changes in the state of permafrost soils, reduction of ground cover moisture, frequency, intensity and timing of fires. According to the results of field studies, larch forests on foothill and intermountain depressions in combination with dwarf birch and valley meadows, as well as larch and birch forests of forb type with shrub undergrowth on foothill uplands were the most disturbed by fires. With burning of trees, undergrowth of conifers and burned ground cover, there was thinning of stands and acceleration of natural bush formation and prairification, typical for the Baikal-Dzhugdzhur type landscapes.

The obtained field data allow to specify local and regional patterns of Baikal-Dzhugdzhur ecosystems dynamics and use them to forecast landscape-ecological assessments under various climatic scenarios.

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