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Zonal Peculiarities of Forest Vegetation Controlled by Fires in Northern Siberia

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Abstract

In the northern part of central Siberia (67-72°N), forest vegetation develops on soil with a thin active layer of permafrost (less than 1 m), where the tree canopy is sparse irrespective of the stand density. This almost excludes competition for light and the leading role is root competition in the forest stands, where shrubs successfully compete with the canopy trees. Throughout the processes of stand formation, self-thinning continues in all size classes. Because the sparse forest vegetation is essentially different from the other taiga zone, it should be distinguished as a special natural vegetation zone: northern open forests zone instead of a subzone of the northern taiga. In this zone, the probability of forest fires is very high, in particular, inflammable conditions occasionally occur in summer and fire rapidly spreads over vast territories excluding mountainous regions. Permafrost has a great indirect influence on the wildland fires by means of a peculiar hydrological regime of this area and the ground vegetation types.

Key words: northern forests, Siberia, permafrost, surface topography, wildland fire

Introduction

Climatic conditions are ecologically the most important factors impacting the differentiation and character of the vegetation cover on a global scale (Archibold 1995), in particular, climatic and weather fluctuations during drought periods affect the vegetation not only directly but also indirectly owing to a pyrological factor. In Siberia, the area of permafrost is not homogeneous in ecological respects of vegetation. For instance, in the southern part, the depth of active layer often reaches 2 m or more in summer, and the mutual influence of permafrost and vegetation, and that of permafrost and wildland fires are faintly expressed. On the other hand, in the northern part of Siberia, the soil usually thaws out to less than 1 m in depth and the mutual influence among permafrost, vegetation and wildfires is very great, resulting in the development of unique forest ecosystems. These peculiarities give full reason not to assign the timber vegetation on permafrost soils with a shallow active layer in the same category as taiga forests, but to consider this vegetation as an independent zonal type (Sofronov 1991a, Sofronov and Abaimov 1991). Such ideas have already been published in former reports (Kolesnikov 1969, Parmuzin 1979).

To clarify the regional vegetation types under consideration, we used the known term as northern open forests, since the most characteristic trait of this zonal type is the sparse forest canopy, which is also seen on aerial photographs. In central Siberia, the area with a sparse canopy extends from the south up to the basin of Podkamennaya River. Northern taiga forests conspicuous with their dense canopy in the open forests are located in a pachwise pattern within this zone which are in river valleys and in sites with relatively warm condition in soils. However, northern open forests are located southward in the mountainous relief of the taiga zone.

There have been few pyrological studies in the northern open forest zone of Siberia to date. Stepanov (1985) dedicated to reforestation with natural regeneration of burnt areas in northwestern Yakutia, whose activities were published in the book entitled "Forest Fires in Yakutia and Their Influence on the Nature of Forests". Matveev (1992) studied the consequences of wildland fires in

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the basins of the rivers Kheta, Lower Tunguska, Lena, and Kolyma. Tsykalov (1987, 1991) collected data of fire experiments on fuel loading in the region of Tura, and estimated the damage to larch stands. Fire consequences and regeneration in burnt-over areas of the same region are being studied by Tsvetkov (1994, 1998) and researchers of Laboratory of Permafrost Forest Science together with Japanese colleagues (Abaimov *et al.* 1997, Abaimov and Prokushkin 1996, Sofronov *et al.* 1999).

In this report, we summarize the former research activities on permafrost vegetation from the viewpoint of fire ecology. We contribute our basic studies to understand the complex ecosystems developing throughout eastern and central Siberian region.

Materials and Methods

Investigations were carried out in the basins of the rivers, e.g. Turukhan, Khantayka, Kheta and Kotuy, and also watersheds of Lower Tunguska, westwards and northwards of the Tura Settlement during 1986-1997. We made some experiments on the study plots of Sofronov (1988, 1991b) and Sofronov and Volokitina (1996a). A complex picture of mutual influence among permafrost, fires and vegetation is shown in this paper based on the analysis and generalization of our data and those of referenced reports. Depth of the active soil layer and the thickness of organic layer on the burnt stands were investigated in the region of Degigly River, 90 km downstream from the Tura Settlement, in 1991 and 1992, and the adjacent settlement of Tura in 1995 (Table 1).

Results and Discussion

One of the characteristics of permafrost is its saturation with ice: i.e. ice veins and lenses are contained in the permafrost, and the ice content (mass) in the uppermost layer usually corresponds to the maximum moisture capacity of the given ground (Pozdnyakov 1986). A high ice content of the permafrost causes specific phenomena such as thermokarst and frost heaving. This is the main difference between permafrost and seasonal frozen soil that retains its porosity. Seasonal frozen soil can actively absorb melting water in spring, while permafrost with its high ice content does not absorb water and represents a waterproof layer. In the northern part of West Siberia, melt water runs off to rivers, so that during a period of about six weeks after the snow melt, fires do not practically occur in the permafrost area, except for limited inflammable sites covered by dry herbs and sedges in riverside and frost mound bog.

The main factor raising the permafrost table is the accumulation of organic matter on the soil surface composed of mosses, lichens and plant litter. The organic layer hardly prevents the soil from cooling in winter, but the layer actively prevents the soil from heating due to its reduced heat conductance in summer, and consequently it plays an important role as an insulator. The ground surface of the northern open forests is usually dominated by feather-mosses and lichens, which increase the danger of flammability, simultaneously with the accumulation of plant litter. According to the increasing in the thickness of the organic layer, the soil becomes progressively colder and the decomposition rate gradually decreases. In the Turukhan basin, for example, the thickness of the organic layer is 8-10 cm in 100-120 years old larch stands with a fuel loading of 4 $kg \cdot m^{-2}$, and those in forest stands of over 200 years old reaches 22-27 cm with

Table 1. Mean depth of active layer dependent on mean thickness of organic layer on soil

Plot no.	(1)	(2)	(2c)	(3)	(4)	(5)	(6)	(7)	(8c)	(8)	(9c)	(9)
Organic layer thickness (cm)	7	7	19	12	15	16	23	19	17	5	5	3
Soil thawing depth (cm)	47	59	30	47	49	9	44	50	25	60	43	51
Length of transect (m)	300	40	40	40	30	30	30	30	20	20	20	20
Observation period		July, 1992				July, 1991				July, 1995		

Notes: (1) burnt area in 1990, the lower position of the northern slope (10-20 °); (2) burnt area in 1990, river terrace; (2c) dwarf shrub-greenmoss and larch forest (control to (2)); (3) overburnt area in 1975 on the river terrace; (4) Ledum-greenmoss larch stand on the flat eminence; (5) alder-greenmoss and larch stand on the low part of the southern slope (8 °); (6) shrub-moss larch stand on the river terrace; (7) Ledum-lichen-greenmoss larch stand with on the convex slope; (8c) shrub-greenmoss larch stand on the northwest slope (12 °) of a stream valley; (8) larch stand damaged by the fires in August, 1994; (9c) larch stand with hollow-mound; (9) larch stand of damaged by the fire in August, 1994

a fuel loading of 6.5-7.5 $kg \cdot m^{-2}$. In the other regions of the zone within the limits of West Siberia, the fuel loading of the feather-moss carpet together with plant litter and lichens varies from 2.5 to 8 $kg \cdot m^{-2}$. The depth of summer thawing of permafrost increases in burnt-over areas where the organic layer has been removed by the fire. However the post-fire increase of the thickness of the active layer is a temporary phenomenon and it provides a suitable environment for the enhanced growth rate of seedlings and understorey shrubs on the burnt areas. In the burnt area investigated in 1982 in the basin of the Nidym River, the height of shrubs in a 12-13 years-old larch stand was 2-2.5 m, where canopy trees reached to 4-5 m. After the recover of the moss and litter layer, about 30-50 years later, the thickness of active layer decreases again.

Rain and snow provide soil moisture in the northern open forest zone, and the soil regimes vary according to the surface topography. We offer the following classification of the surface topography by their drainage patterns and moisture content: 1) convex, 2) crest flat, 3) slope, 4) concave (depression, hollow, valley of rill, etc.), and 5) bottom flat (terrace, river plain). In this forest zone, if the watershed is located below the level of mountain tundra, large wildfires often occur since there are no upper sphagnum bogs, which are fire resistant landscapes. Heaving of permafrost is observed under patches of sphagnum. As a result, the sphagnum ceases its growth and gradually dies out. Favorable conditions for sphagnum develop only with a moisture supply from outside the area, e.g. from lateral water movement. Such sphagnum patches of 5-10 m^2 usually do not die during fires, and actively begin to grow up again. We often found sphagnum patches of about 1 ha on the north-facing slopes. However, these were not swamps since an ice body was always formed under the sphagnum layer, although small sphagnum bogs sometimes develop in the upper part of head hollows as well as on lower side slopes and on hillside terraces.

Swampy areas of the northern open forest zone in Central and East Siberia occupy only about 4-6% of the total area. Sites with an increased moisture regime, which are favorite habitats for sphagnum in the taiga zone, are usually covered with feather-mosses. These mosses tend to more desiccated than sphagnum and to dry up more rapidly, resulting in the increase in the danger of natural fires in these areas.

In the northern part of West Siberia and Taymir, the development of cracks and depressions are promoted by frost, resulting in the appearance of swampy areas, lots of small lakes and puddles. The sites among lakes are relatively dry because of the well-drained conditions. Such a landscape is called "frost-mound bogs", and about 80% of this area of northern West Siberia is occupied by such well-drained frost mounds. The mounds comprise of an ice body with a mixture of peat, and have been found tobe covered both by lichens with 1.5 $kg \cdot m^{-2}$ biomass and by *Ledum* species with 1 $kg \cdot m^{-2}$ biomass, indicating that fire danger of the mounds is very high. However, these areas have rather low danger of fire because of thermokarst lakes and humid hollows occupied by sedge-sphagnum mires. The average distance among thermokarsts is about 1 km (Sofronov 1988). Though the mounds are covered by typical tundric vegetation, there are no swampy elements, and such landscapes are complexes of swamp-forest tundra (Shumilova 1962). Overall, the northern part of West Siberia is considered as a swampy area, but this true swampy area hardly exceeds 15%. In this way, a low vulnerability to fire due to the swamps is noticeable in the northern open forest zone.

In the southern part of Central and East Siberia, the altitudinal timber limit is about 800 m, and northward it goes down to about 400 m, and even to 200 m in Anabar. The mountainous tundra zone is situated between 1100 and 1200 m, and in the area higher than the mountainous tundra zone where the cold stony tundra zone develops. In Putorana, the mountain tundra is non-continuous and forms like patchy "frost boiling" within the stony tundra, which plays a role as fire breaks in mountainous open forests.

We did not find out any clear relationships between wildfires and thermokarst, but wildland fires quite often cause the development of a peculiar landform of thermokarst on steep slopes. For instance, spring waters and heavy showers erode the soil after the removal of the organic layer by fire, resulting in the beginning of the permafrost to thaw, and this intensifies the soil movement and prevents forest floor and plant litter from accumulation. Mud streams may develop where the permafrost has melted deeply, particularly in the places thawed out with underlying large ice lenses. Periodically, the thawing causes soil movement. The depth of the active layer depends on thermal insulation properties of the surface organic layer, which consists of mosses and lichens. The insulating effect and porosity of the organic

layer determined by the soil moisture regime, thus the ice lens is protected by the active layer and by a moss and plant litter layer. Since the moss and plant litter become very efficient heat insulators, the permafrost usually does not thaw deeply during the drought summer. The drought conditions of moss and plant litter make the banks of stream areas considerably prone to fire, resulting in the probability of fires spreading over large areas. The second important factor determining the thickness of the active layer is the ice content of soil in spring, because ice melting consumes a large amount of heat (90 $cal \cdot g^{-1}$). The spring ice content of soil directly depends on the soil moisture content before freezing in autumn.

Our investigations on the burnt stands show that the average depth of the active layer depends on the thickness of the organic layer on the soil (Table 1). For example, in a larch, stand covered by *Ledum* and feather-mosses (plot no. 8c), the depth of the active layer in early August of 1995 was only 25 cm, and the average thickness of the organic layer was 17 cm, while the depth of the active layer in another larch stand which had experienced surface fires in 1994 was 72 cm with only 5 cm thickness of the organic layer (plot no. 8). On the burnt area in 1990, the depth of active layer on north-facing slope (plot no. 1) changes. Well-developed surface topography changed the drainage and the depth of active layer on the burnt sites (plot no. 6 and 7). In northern Siberia, the difference between higher surface air temperature and lower soil temperatures is very large (Sukachev 1931, Pogrebnyak 1955). Therefore, the temperature regime of the soil becomes an ecologically independent factor, which is expressed as the depth of the active layer.

Consequently, the scheme of forest vegetation conditions in the northern open forest zone may include the following three factors: 1) temperature regime of soil, 2) water regime of soil, and 3) soil fertility (nutrients). These factors affect each other and depend on other factors (Sukachev 1931). Also there is a complex relationship between the water and temperature regimes of soil.

A schematic diagram of the complex relationships among different factors and vegetation biogeocoenoses on permafrost in northern Siberia is shown in Fig. 1. When the soil thaws to less than 1 m in depth, the rooting zone is reduced and the volume of living roots per unit area decreases. Because the above ground biomass is directly associated with the living root biomass, the

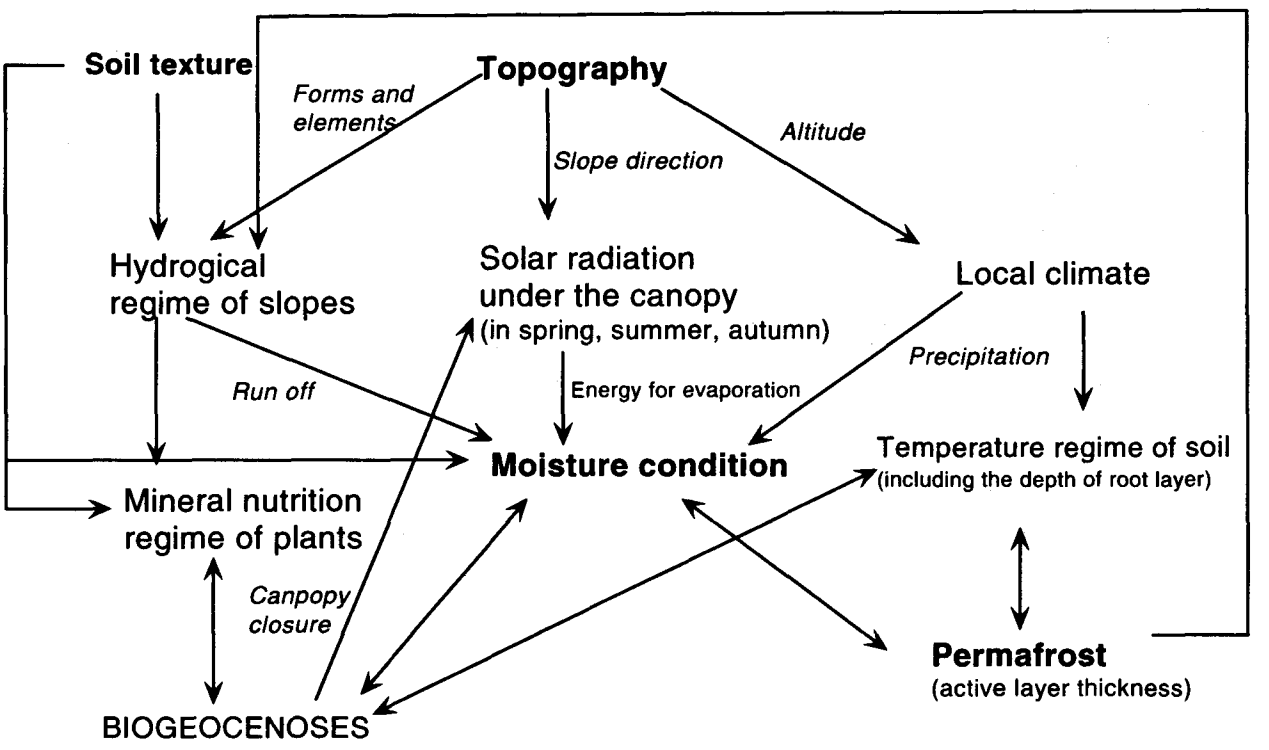

Fig. 1. Schematic diagrams of relationship environmental factors, and their influence on biogeocenoses in the northern open forest zone in Siberia.

Table 2. Interaction of fire and permafrost

Permafrost	Influence	Wildland Fires	
Absence of ground water and drainage	negative on spring fires	wet condition of moss and litter in spring	low danger of fire
		drought condition of moss and litter in summer	high danger of fire
	positive on summer fires	the absence of upper sphagnum swamp	high danger of fire
Small tree crown	positive on summer fires	light condition and wind to the forest floor	drought and intense combustion
increasing active layer thickness less insulation soil movement	negative on permafrost	Combustion of moss floor and plant litter	

tree canopy is always thinner in northern open forests regardless of the tree density.

Measurements of light intensity showed that the quantity of radiated energy and light intensity under the canopy of open larch stands are 1.5-3 times higher than those in typical taiga stands (Sofronov and Volokitina 1998), indicating that there is minimal light competition in northern larch forests. Because adequate light condition considerably changes the development of forest biogeocoenoses, regularities in stand structure may change the distribution of trees (Abaimov and Sofronov 1996). In the seedling and sapling stage, the self-thinning process is considerably slowed down. For this reason, the exceedingly abundant and naturally regenerated seedlings of the canopy trees in burnt areas may result in "permanent" young and pole stands.

Wind, the main factor of spreading fires, freely penetrates through the thin canopy of northern open forests. Surface fires may be exceedingly intense with a flame height of more than 2 m in early summer. When plant litter layer has dried out in late summer, surface fires smolder in the plant litter. Higher above this zone, a boundary layer of hot air mass keeps the wind off the flame edge. As a result, creeping surface fires spread slowly in this zone. Severe surface fires damage the root system of trees very much, since almost all the roots are concentrated in the litter layer. That is the most important cause of the high tree mortality by fire in the boreal regions.

Although wildland fires reduce the thickness of moss and plant litter layer, fire creates favorable conditions for biomass productivity. The optimum thickness of the organic layer for seed germination is 2-4 cm in the burnt area, but a thickness of over 6 cm rather prevents germination (Sofronov and Volokitina 1996b). Therefore, mutual effects of permafrost, vegetation and wildfires are very significant and diverse (Table 2). Although lightning is the main cause of forest fire, there is no official information on the relative burnt areas in the northern part of Siberia. According to the analysis of space images (Sofronov *et al.* 1998), the probability of forest fire is very high: approximately 1.3-1.5 % area of the forest territory of central Evenkia per year.

Conclusions

In the northern part of Central Siberia, the continental climate characterized by very severe winters and warm summers contributes to the development of timber vegetation on permafrost soils. The main ecological factor is the temperature regime of the soil expressed by the active layer thickness. It depends on the ice content of the soil in spring and on the thermal insulation properties of the organic layer. Soil temperature regime makes peculiar soil moisture regime and stand structure such as thinness of tree canopy. Forest vegetation of this unique zone is essentially different from the typical taiga zone of Siberia. Therefore, the forest zone should be distinguished as a special natural zone, in which the permafrost depth is greatly influenced by the fires by means of a peculiar hydrological regime of the area and the characteristics of ground vegetation types. Favorable conditions may be created for the spread of fire over vast areas except for mountainous regions. Fires increase the depth of the active layer due to the removal of the organic layer, which insulates heat into the soil in summer but prevents the soil from cooling in winter. On steep slopes, fires quite often cause soil erosion, and consequently the probability of

forest fire in the northern open forest zone is very high.

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References

Abaimov, A.P., Kanazawa,Y, Prokushkin, S.G. and Zyryanova, O.A.(1997) Postfire transformation of larch ecosystem in Siberian permafrost zone. *In:* G. Inoue and A. Takenaka (eds.), Proceedings of the Fifth Symposium on the Joint Siberian Permafrost Studies between Japan and Russia in 1996, 129-137.

Abaimov, A.P. and Prokushkin, S.G. (1996) Alteration of larch stands vital sate in the permafrost zone of Central Siberia under fire influence. *In:* M. Fukuda (ed.), Proceedings of the Fourth Symposium on the Joint Siberian Permafrost Studies between Japan and Russia in 1995, 57-64.

Abaimov, A.P. and Sofronov, M.A. (1999) The main trends of post-fire succession in near-tundra forests of Central Siberia. *In:* J.G. Goldammer and V.V. Furyaev (eds.), Fire in Ecosystems of Boreal Eurasia, 372-386. Kluwer, Dordrecht.

Archibold, O.W. (1995) Ecology of World Vegetation. 510p. Chapman and Hall, London.

Kolesnikov, B.P. (1969) Forestry regions of the USSR taiga zone and systems of forestry for long term forecast. Information of Scientific Counsel on Complex using of Forest Regions, 9-39. Irkutsk. (in Russian)

Matveev, P.M. (1992) Fire consequences in larch forest in permafrost zone. Abstract of Doctor Thesis. Yoshkar-Ola, Polytechnic Institute, 50p. (in Russian)

Parmuzin, Y.P. (1979) Tundra-forest zone of the USSR. 396p. Misl Press, Moscow. (in Russian)

Pogrebnyak, P.S. (1955) Fundamentals of forest typology. 30p. Kiev, Acad. Sci. UkrSSR Press. Moscow. (in Russian)

Pozdnyakov, L.K. (1986) The permafrost forestry. 130p. Nauka, Novosibirsk. (in Russian)

Shumilova, L.V. (1962) Botanical geography of Siberia. 440p. Tomsk State Univ., Tomsk. (in Russian)

Sofronov, M.A. (1988) Pyrological characteristic if vegetation in the upper part of the river Tyrukhan basin. Forest fires and their fighting, 106-116. VNIILM, Moscow. (in Russian)

Sofronov, M.A. (1991a) Forest forming process on cold soils and its relation with fires. Ecological and geographical problems of protection and restoration of northern forests, 169-171. Abstracts of the All-Union Conference, Arkhangelsk. (in Russian)

Sofronov, M.A. (1991b) Pyrological characteristic of forest in the south-east of Tymir. Forest fire and their fighting, 205-211. VNIILM, Moscow.

Sofronov, M.A. and Abaimov, A.P. (1991) The forest forming process peculiar features on the frozen soils. The theory on the forest forming process. Abstracts of the All-Union Conference, 154-155. Arkhangelsk. (in Russian)

Sofronov, M.A. and Volokitina, A.V. (1990) Pyrological regions of the taiga zone. 204p. Nauka, Novosibirsk. (in Russian)

Sofronov, M.A. and Volokitina, A.V. (1994) Forecasting regional pyrological situation in boreal forests under Global climate change. *In:* R.G. Khlebopros (ed.), The Program East-East Global Regional Ecological Problems, 40-47. Soros Foundation, Krasnoyarsk.

Sofronov, M.A. and Volokitina, A.V. (1996a) Vegetation fires in the zone of northern thin forests. Siberian Journal of Ecology, (Vol. III), 1: 43-50.

Sofronov, M.A. and Volokitina, A.V. (1996b) The role of fires in forest restoration of cutting down areas in the North of Central Siberia. Forestry, 6: 50-51. (in Russian)

Sofronov, M.A., Volokitina, A.V. and Kajimoto, T. (1999) On the investigation of postfire biomass dynamics in the northern ecosystems of Siberia. *In:* M. Fukuda (ed.), Proceedings of the 4th Symposium on the Joint Siberian Permafrost Studies between Japan and Russia in 1995, 45-50.

Sofronov, M.A., Volokitina, A.V., Shvidenko, A.Z. and Kajimoto, T. (1998) On area burnt by Wildland fires in the northern part of Central Siberia. *In:* S. Mori *et al.* (eds.), Proceedings ofthe 6th Symposium on the Joint Siberian Permafrost Studies between Japan and Russia in 1997, 139-146.

Stepanov, G.M. (1985) Forest forming on post fire areas in the northern taiga of Yakutia. Abstract of PhD thesis. Krasnoyarsk, Inst. of Forest and Wood, Sib. Dept. Acad. Sci. USSR, 17p. (in Russian)

Sukachev, V.N. (1931) Guidance for the forest types investigations. 328p. State Press of Agriculturel Literature, Moscow-Leningrad. (in Russian)

Tsvetkov, P.A. (1994) On height of smoked part of trees after fires in larch forests of Evenkia. Lesovedeniye, 4: 90-93. (in Russian)

Tsvetkov, P.A. (1998) Pyrological characteristic of larch forests of Evenkia. Forestry, 6: 45-46. (in Russian)

Tsykalov, A.G. (1987) Fire dander of larch forests of Central Evenkia in correlation with load of surface forest fuel. *In:* Forest fire and their fighting, 226-238. VNIILM, Moscow. (in Russian)

Tsykalov, A.G. (1991) The nature of fires in forests on permafrost zone of Central Evenkia. 26p. Ph.D. Thesis of Krasnoyarsk, Inst. of Forest and Wood, Sib. Dept. Acad. Sci. USSR, Krasnoyarsk. (in Russian)