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Forest Fires Impact on Microclimatic and Soil Conditions in the Forests of Cryolithic Zone (Yakutia, North-Eastern Russia)

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Data analysis on the fire occurrence and frequency in Central Yakutia (North-Eastern Russia) has been considered. Calculate the impact of socio-economic and climatic conditions of region on inflammability parameters. A close relationship was found between quantity and density of population and the frequency of fires occurence (0.95–0.99). Not so much negative correlation observed between the amount of precipitation during the fire-dangerous period and the frequency of fire (–0.53). The results of our study relating to the fire impact on microclimatic and soil conditions of the forests of Central Yakutia are brought in the article. Studies have revealed that strong changes microclimate and soil conditions in the burnt areas occur in the first 10 years after the fire. At the young burned out site, soil temperature in average increases in comparison with the forest at a depth of 5 cm in 5.2 ... 5.6 °C, at a depth of 30 cm – in 4.3 ... 6.2 °C, soil moisture – by 1.1–2.3 times in a 1–2-year – fire site, by 1.1–1.7 times in a 10–12-year-old one; seasonally thawed layer thickness is 0.3–0.8 m greater in the burned out areas than in the forest. There is stabilization of the modified conditions in the post-fire period in the course of succession. Essential changes of microclimatic and soil conditions occurring after fires and stabilizing in the progress of succession when fire-sites overgrow with plants have been found. In the burned areas of the Central Yakutia it starts at the age of 20–25 years after the fire.

Keywords: *cryolithozone, forest fires, burnt-out areas, fire-site, Yakutia.*

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INTRODUCTION

One of the most common and destructive factors in the forests of a boreal zone are forest fires. Fires are natural phenomenon in boreal forests (Utkin, 1965; Scherbakov et al., 1979; Sannikov, 1983; Abaimov et al., 1996; Furyaev, 1996; Prokushkin, Zyryanova, 2013 etc). That is why the normal ecological functioning of the forests is determined by fires. Yakutia, one of the largest Russian regions in the North-East, is particularly vulnerable to forest fires (Scherbakov et al., 1979; Yakovlev, 1979; Timofeyev et al., 1994). Over 8.2 thousand fires were recorded in Yakutia during the last 10 years, covering 1.3 million ha and resulting in 20 million m^3 of burned out timber (Lytkina, Isaev, 2010). Fires bear both anthropogenic and natural causes of their appearance in the forests of Yakutia. The natural features of the region – combination of permafrost and lack of atmospheric moisture and dry climate – generate natural causes for the emergence and spread of forest fires. The economic development of the region plays an important role in the process of forest-formation in Yakutia. The role of humans in the emergence and spread of forest fires is increasing for the recent years.

An analysis of the forest fire statistics reveals that the primary cause of forest fires in Yakutia is thunderstorms in July-August (over 50 %). These are so called «dry thunderstorms», specific for Yakutia. A thunderbolt induces ignition of the ground cover and dead wood. Lightning-caused fires usually affect the largest areas of forest tracts owing to their remoteness and difficulty to access the location. A little less then half of all fires are induced by a man, especially in densely populated and industrial regions. Their amount increases during the intensified recreation periods (agricultural work, spring and autumn hunting, outdoor leisure, harvesting berries and mushrooms, etc.).

In the forests of Yakutia ground (surface) fires are most common. Quick spring fires destroy last year's herbal vegetation, and partly also the fresh tree waste and other dry plant remains, having a minor negative effect on the forest communities. Settled ground fires, however, are more dangerous because of the complete elimination of lower layers, i. e. herbage, shrubs, and young trees. Tree stands remain untouched for 10–90 %. After the total or partial destruction of the litter and soil-vegetation cover, the heat, moisture, radiation and permafrost conditions of soils change drastically (Utkin, 1965; Pozdnyakov, 1963*a*, *b*; Gavrilova, 1967, 1969; Savvinov, 1971; Tarabukina, Savvinov, 1990).

Peculiarity of the burned out forests lies in changes of soil conditions, occurrence of post-fire remains (dead standing and fallen trees) and specifically developing post-fire vegetation.

In the issue of deforestation in the cutting areas and forest fires in burnt-out territories there is an increased access of solar energy and precipitation to soil. It leads to changes in microclimatic and soil conditions on burnt-out areas: temperature and moisture regime of the soil and air (Zyabchenko et al., 1988). And in different natural and climatic areas the vegetative ground cover and therefore fire frequency are different, which causes the difference of soil conditions and features in different forest sites.

Thereupon studying the dynamics of vegetable cover restoration of uneven-aged burned-out forests of the Lena-Amga inter-stream area we found it necessary to observe the change of microclimatic conditions on burnt-out areas after lasting fires among the alases (alas is a closed or semi-closed thermokarst depression developed on upland flat spaces in the area of permafrost distribution (Bosikov, 1991)) where the so called ice complex is widespread.

The aim of this work is to analyze statistical data on forest fires and to study changes in the forest vegetation (microclimate and soil) after the post-fire period.

MATERIALS AND METHODS

The statistical data on forest fires relates to the period from 1974 to 2011.

We studied the burned out areas of different age: 1–2, 10–12, 20–23, and 58–60 for three years (2002–2004). The cowberry larch forest was chosen as a control area – the most prevalent type of the forest of Central Yakutia in East Siberia. Study of microclimate and partly soil indicators on uneven-aged burned-out forest sites (fire-sites) was conducted on the following parameters: air temperature on the soil surface, soil temperature at depths of 5, 10, 15, 20, 30, 40, 50, 100 cm, air humidity, soil moisture, depth of the seasonally thawed layer (STL) of soil. The standard meteorological (weather) equipment was used: weekly thermographs, hygrographs, mercury and alcohol thermometers (urgent, max, min), Savvinov's knee thermometers, electric thermometer AM-29, sound thermometer probe, balance.

Measurements were carried out in 3 cycles: early in June, mid-July, late in August. Every cycle lasted a week with triple measurements – in the morning (8–9 a. m.), in the day-time (1–2 p. m.), and evening (8–9 p. m.) and additionallyonce per cycle the diurnal measurement with a 3-hour interval was carried out.

Soil studies – soil moisture and the STL depth – were measured once per cycle. Study of soil moisture was conducted with a gravimetric method in three replications at depths of 5, 10, 20, 30, 40, 50 cm (Rode, 1969).

Data processing is performed using the computer program Excel.

The observations were made in 3 years (2002–2004) in 4 sites.

The subjects of research are located in the neighborhood of Matta village, Megino-Kangalassky ulus (district) of the Sakha (Yakutia) Republic that is 100 km northeast of Yakutsk – the capital of the Republic, in the Lena-Amga interfuve, on the right Lena riverside – one of the largest rivers of NE Asia.

A 1-year old fire-site is 7 km west of Matta vil, Megino-Kangalassky ulus, 200 m north of Ontoon Toburuone alas. It is a completely burnt out part of the forest with a grassy community of the open type with participation of pioneer species. The microrelief is smooth with occasional thermokarst subsidence. Strong soil overmoisture has been noted. Larch self-sowing is not abundant, annual, 5–7 m high. One hectare of the area comprises 10 000 sprouts of *Larix cajanderi* Mayr and 5 000 sprouts of *Betula pendula* Roth. *Chamaenerion angustifolium* (L.) Scop. (cop^3) takes prevalence in the herbage. *Tephroseris palustris* (L.) Reichenb. (sol) grows in the places with moisture excess. *Corydalis sibirica* (L.) Pers. (sp) and *Carex* sp. (sol) also occur, while *Crepis tectorum* L., *Vicia cracca* L., *Limnas stelleri* Trin. are single inclusion. *Vaccinium vitis-idaea* L. and *Arctous erythrocarpa* (Small) M. Ivanova sprouts are patchy. The total projective cover of herbage averages 50 % in this fire-site. There are favorable conditions (wet soil medium, good light intensity) for pioneer moss species *Marchantia polymorpha* L. (cop^2) to grow.

A 10-year old fire-site is located southwest of Matta vil., Megino-Kangalassky ulus on a flat area between Bulgunnyahtah and Keltegeidyah alases. The fire-site is at the stage of motley grass-grasses association with participation of shrubs. The forest stand burnt out totally (95 %). Willows – *Salix bebbiana* Sarg., *S. pseudopentandra* (B. Floder.) B. Floder., *S. pyrolifolia* Ledeb., *S. viminalis* L., *S. brachypoda* (Trautv. et C. A. Mey.) Kom – dominate in the young tree growth averaging 1.4 m high. There is also a young tree growth consisting of *Betula pendula* Roth and thin *Larix cajanderi* Mayr. More developed tree growth of *Larix cajanderi* Mayr occurs in the northern and western part of the fire-site: 40 000 young trees/ha, average height 1.8 m, 1 cm in diameter, age – 3–8 years. The herbaceous-shrub layer is represented by *Limnas stelleri* Trin. (cop^3), *Rubus arcticus* L. (cop^2), *Vicia cracca* L. (sp), *Sanguisorba officinalis* L. (sol), *Stellaria longifolia* Muehl. ex Willd. (sol), *Inula britannica* L. (sol), *Poa pratensis* L. (sol), *Potentilla anserina* L. (sol), occasionally – *Chamaenerion angustifolium* (L.) Scop., *Taraxacum ceratophorum* (Ledeb.) DC., *Lupinaster pentaphyllus* Moench., *Equisetum pratense* Ehrh., *Plantago canescens* Adams, *Euphrasia jacutica* Juz., *Viola mauritii* Tepl. and etc., *Vaccinium vitis-idaea* L. occurs as small patches. The total grassy projective cover attains 70–80 %. Moss-lichen cover is sparse reaching 15 % with prevalence of *Marchantia polymorpha* L. and occasional *Dicranum* sp.; lichens present species of the genera *Flavocetraria, Cladonia,* etc.

A 22-year old fire-site is located 13 km southwest of Matta vil, Megino-Kangalassky ulus, 100 km southward of Ulakhan Kuruoleeh alas. The area occupies the southern side of the alas extending further southwest as flat space between alases being at the stage of the birch-larch young trees with sparse herbaceous-shrub cover. Fallen trees are typical, heaps of half-decayed wood pile up over 90 % of the fire-site area. The young tree growth is very closed and overstocked. Estimation for *Larix cajanderi* Mayr and *Betula pendula* Roth is 200 000 and 60 000 specimen/ha, respectively. Because of the overstocked stand the growth of young trees is inhibited. Larch height averages 1.7 m, lower than 1 cm in diameter. The maximal tree height attains 3.2 m. The underwood is not developed, willows are occasional. Forest species *Vaccinium vitis-idaea* L. and *Linnaea borealis* L. take the leading place in the herbaceous-shrub cover (to 25 % of coverage). *Limnas stelleri* Trin. (sol) occurs together with suppressed low-sized *Chamaenerion angustifolium* (L.) Scop.

A 58-year-old fire-site takes an extensive territory from Usun-Ebe alas (7 km southwest of Matta vil.) to Mandygytta alas (10 km east of Matta vil.). The site under study is 3 km southeast of Matta vil. and east of Khatyngnah alas. The microrelief is smooth. The plant carpet is represented by polewood (density 0.6–0.7) with height averaging 7–8 m and 8.2 cm in diameter. One hectare holds 1500 larch trees. The young tree growth is uneven subdivided into 2 generations: to 2 m and from 2 to 4 m high. The underbrush is not developed. *Rosa acicularis* Lindl., species from genus *Salix* occur as single inclusion. The herbaceous-brush belt comprises the forest sp – *Vaccinium vitis-idaea* L., *Linnaea borealis* L., *Pyrola asarifolia* Michaux, *Orthilia obtusata* (Turcz.) Jutrz. with the total projective cover coming to 80 %. *Lathyrus humilis* (Ser.) Spreng., *Limnas stelleri* Trin. are also scarce. Moss-lichen cover is composed of *Aulacomnium turgidum* (Wahlenb.) Schwaegr., *Ptilidium ciliare*

(L.). Hampe, *Dicranum polysetum* Sw., *Rhytidium rugosum* (Hedw.) Kindb., *Peltigera canina* (L.) Willd., *P. leucophlebia* (Nyl.) Gyelu., species from the genus *Cladonia.*

Cowberry larch is a widespread forest type growing over extensive interstream areas of the frozen taiga pales, weakly solodic loamy soils. The site examined is 1 km southwest of Matta vil., Megino-Kangalassky ulus, between the Bulgunnyahtah and Keltegyaidyah alases near a 10-year old fire-site occupying the flat interalas space. Clean or mixed with birch low productive larch stands (70 years old, 12 m high, 12 cm in diameter) are typical for it, weakly developed young growth (0.66 ths specimen/ha). In many cases the undershrub layer is absent or *Rosa acicularis* Lindl., species of the genus *Salix* scarcely occur. There is a developed continuous cowberry (*Vaccinium vitis-idaea* L.) carpet with a touch of the forest species (*Pyrola asarifolia* Michaux, *Orthilia obtusata* (Turcz.) Jutrz., *Linnaea borealis* L.) and weakly developed moss-lichen cover of *Aulacomnium palustre* (Hedw.) Schwaegr., *A. turgidum* (Wahlenb.) Schwaegr., species of the genera *Dicranum, Cladina, Cetraria*.

RESULTS AND DISCUSSIONS

Forest fires in the Lena-Amga interfluves

According to the information of the Department of Forest Affairs under the Ministry of Nature Protection of the Republic of Sakha (Yakutia), since 1974 to 2011 over 3973 forest fires were recorded in the area embracing 936 180 hectares on the territory of the Lena-Amga interfluve. On the average, from 13.5 to 33.9 fires were registered in the area of 1752 to 12 900 ha yearly.

Average fire occurrence values of the Lena-Amga interfluve forests make 0.403 % over a 38 year period. The data brought in table 1 suggest a significant increase of the relative forest occurrence from 0.013 (1974–1983) to 0.745 % (1994–2003).

Forest fire occurrence changes are shown in Fig. 1, indicating a trend of inflammability growth during the recent years. The statistics are confirmed by a linear trend, which is presented on the graph. Within a 38-year period there were 4 forest fire peaks over this area – in 1987 (1.564 %), 1992 (1.115 %), 2002 (5.39 %) and 2011 (2.895 %); 1975 (0.0005 %), 1976 (0.0005 %), 2000 (0.0006 %) and 2007 (0.0007 %) are characterized as years with minimal forest fire occurrence. Inflammability increase or decrease depends on weather conditions in the present fire hazardous season and it depends more on the precipitation total than on the air temperature. Thus, years with the maximum fire occurrence (1987, 1992, 2002, 2011) had the minimum precipitation total during the fire hazardous seasons (135.5, 103.0, 82.0 and 153.9 mm, respectively). The tendency of the precipitation total decrease per year is similar to the precipitation total during the fire hazardous season. Table 2 shows the pattern of the regional forest inflammability.

The forests near Yakutsk (20.61 fire cases/100 thousand ha and 0.99 %, respectively) and Megino-Kangalassy district (5.55 fire cases/100 thousand ha and 0.17 %, respectively) are characterized with frequency of forest fires and maximum inflammability. The average area of fires in these regions should be noted as relatively medium and low (2.6 and 1.74 thousand ha, respectively), the reason for that is early detection of fire and timely fire extinguishing owing to high density of population (63 persons per square km) and

Table 1. Forest fire occurrence in the districts of the Lena-Amga interfluve and in Yakutsk environs, %

Years	Districts of Central Yakutia						Average over the whole area
	Amga	Megino-Kangalassy	Tatta	Ust-Aldan	Churapcha	Yakutsk	
1974–1983	0.012	0.016	0.022	0.005	0.003	0.022	0.013
1984–1993	0.199	0.132	0.760	0.183	0.016	0.633	0.320
1994–2003	0.159	0.341	0.091	0.171	0.572	3.138	0.745
2004–2011	1.721	0.202	0.434	0.072	0.566	0.199	0.532
Average over 1974–2011	0.523	0.173	0.327	0.108	0.289	0.998	0.403

Note. Fire occurrence is a fire-total area ratio in %.

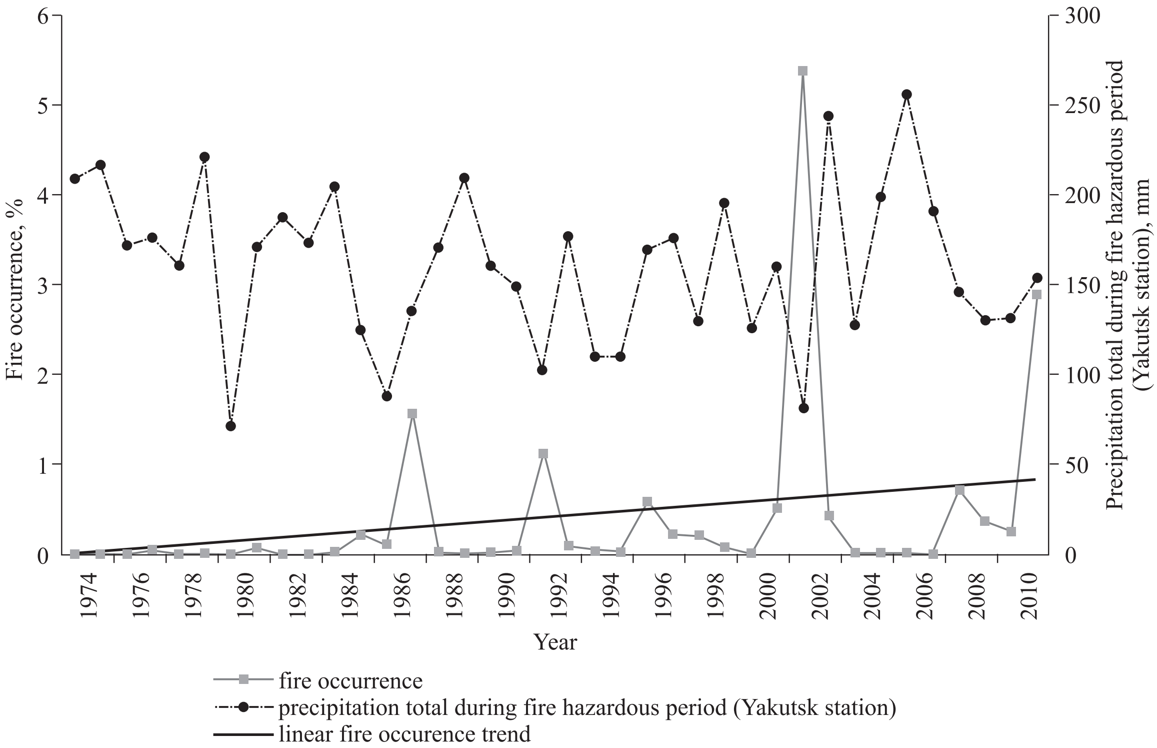

Fig. 1. Dependency of the relative forest fire occurrence on precipitation total in the Lena-Amga interfluves.

Table 2. Characteristic of forest fire occurrence in the Lena Amga interfluve and in Yakutsk environs

Districts	Amga	Megino-Kangalassy	Tatta	Ust-Aldan	Churapcha	Yakutsk
Fire frequency, case/100 thou ha	1.46	5.55	1.55	2.84	2.65	20.61
Fire occurrence, %	0.52	0.17	0.33	0.11	0.29	0.99
Average area of fire, thou ha	12.90	1.74	5.45	1.75	2.97	2.60

developed forest areas. The most favorable in the context of fire breaking out areas are Amga and Tatta districts – less than 2 fires per fire hazardous season. But the average fire area in these regions is the highest – about 5.45–12.9 thousand ha owing to vast unexplored forest areas.

Table 3. Forest fire occurrence and socio-economic and climatic conditions relationship

Indices	Correlation coefficient
Density of population – fire occurrence	0.99
Density of population – fire frequency	0.95
Population abundance – fire occurrence	0.99
Population abundance – fire frequency	0.96
Precipitation total per fire hazardous period – fire frequency	–0.53
Average air temperature per fire hazardous period – fire frequency	–0.17

According to the data collected, correlation coefficients of inflammability indices were calculated considering some climatic and socio-economic conditions (Table 3).

Relation between abundance and density of population with fire occurrence statistics and frequency is expressed by a correlation coefficient 0.95–0.99 that evidences a close relationship among these indices. Correlation coefficient between precipitation total per fire hazardous period and frequency of fire indicates the existing negative relation (–0.53) though it is not very significant. There is no any relationship between the average air temperature and fire frequency (–0.17).

Data analysis on the cause of fire breaking out for a 38-year period on Lena-Amga interfluve revealed (Fig. 2) that the main reason of fires are «dry thunderstorms» in July-August (38.3 %).

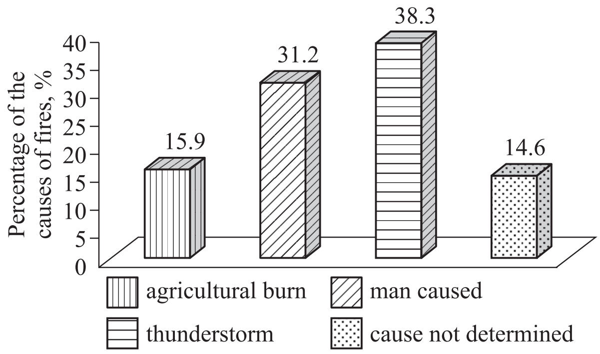

Fig. 2. Causes of fire in the forests of Lena-Amga interfluve and near the city of Yakutsk, in % from the total number.

15.9 % of fires falls on the agricultural burns, a traditional method of pasture preparation in cattle-breeding regions of Yakutia. 31.2 % of fire accidents happen because of casual handling with fire. During recent years a man-caused share of fires has significantly increased. Only in 2002 70.42 % of fires were man-caused. There are also fire cases the origin of which was not determined (14.6 %).

Thus, there always were forest fires in Central Yakutia causing direct or indirect influence on forest ecosystems. Though we did not consider the forest fires statistics at the beginning of the last century, there is reason to believe that forest fires always took place in Central Yakutia and had an influence on the wildlife.

In comparison with the other regions of Yakutia, Central regions have been characterized by particularly high forest inflammability for a long historical time, by reason of not only arid conditions and high density of population but also because of a housekeeping habit in these regions. Agricultural burning of grasslands, pastures and hayfields used to be the main cause of forest fires until recently (Utkin, 1965).

It seems practically impossible to prevent fire breaking out in the permafrost regions which are difficult to take under control by the special forest fire protection services because under weak decomposition of plant litter and deficient mineralization of organic matter in the soil, accumulation of inflammable materials in the forests of the permafrost regions is enough to be the source of forest fire emergence during the arid seasons of the year (Tarabukina, Savvinov, 1990). Forest fires tend to a definite cyclic emergence relating to the climate changeability each year that is particularly clearly expressed in central arid regions of Yakutia (Utkin, 1965; Yakovlev, 1979; Scherbakov et al., 1979; Isaev et al., 2004).

Fire impact on the microclimatic and soil conditions

According to the literature data, all changes in microclimatic and soil conditions depend on changes of the radiation situation in the forest after a fire. In the issue of deforestation and forest fires an inflow of light into the forest floor is increasing (Gavrilova, 1967, 1969; Isaev, 1993; etc). For example, according to M. K. Gavrilova (1973), in Central Yakutia 56 kcal/cm^2 of total radiation penetrates through the crown layer of the larch forests and on the open space it is about 90–100 kcal/cm^2 of heat per year. The major part of luminous flux (54.8–69.5 %) in the forest is blocked by tree crowns. And the greater is the canopy closure, the lower is illumination (8–9 % with each point) (Scherbakov et al., 1979; Isaev, 1993). Besides, the reflecting power of the forest cover amounts to 20 %, while reflectance of dark surface of burnt out spot amounts to 10 % (Gavrilova, 1969).

Fire impact on the ambient temperature. Air temperature measurement is carried out on the soil surface level, where main biological processes occur (from forest fires to plant growth and death).

The temperature conditions of the studied areas are characterized by figures given in Table 4.

The table shows average ten-day (decade) means of the air temperature observed at 8 a. m., 2 and 8 p. m. in the beginning, middle and end of the vegetation period.

Temperature observations in the fire sites showed that the ambient temperature is slightly higher as compared to the one in the control area in the cowberry larch (hereinafter-in the forest). Thus, in 2002–2003, the surface layer of air on burned out areas was warmer than in the forest, by 1.2–1.4 °C in July, by 0.6–1.1 °C in August. The analysis of the diurnal temperature range on the soil surface during the vegetation periods has revealed the following. In the beginning of the vegetation period (06.06.2004–10.06.2004) sizeable fluctuation of the diurnal temperature range has been detected (Fig. 3, *a*). For lack of any vegetation and less shading during the daytime the air temperature in burnt-out areas is much higher

Table 4. Air-ground temperatures in the burned-out areas and in the forest, °C

Year	Site	Observation time (month, decade)	Observation period			Average aily	The average	
			8:00	14:00	20:00		min	max
2002	Fresh burnt-out areas	II decade of July	19.4	23.4	21.2	21.3	11.7	27.7
		III decade of August	10.0	18.7	14.6	14.5	6.0	19.9
	10 year burnt-out areas	II decade of July	19.8	24.3	0.3	21.5	11.2	29.2
		III decade of August	10.1	19.0	15.8	15.0	7.9	20.1
	58 year burnt-out areas	II decade of July	17.8	22.9	19.7	20.1	12.3	25.1
		III decade of August	7.7	15.9	12.0	11.9	6.1	16.8
	Cowberry larch	II decade of July	18.5	21.9	19.9	20.1	10.8	24.9
		III decade of August	9.6	18.0	14.3	13.9	8.0	18.4
2003	10 year burnt-out areas	II decade of July	19.7	30.7	22.3	24.2	12.8	34.0
		III decade of August	7.6	18.3	13.5	13.9	6.6	20.0
	58 year burnt-out areas	II decade of July	13.8	28.2	24.5	22.2	11.5	33.0
		III decade of August	6.5	16.5	14.0	12.3	6.8	17.8
	Cowberry larch	II decade of July	19.7	30.0	26.5	25.4	14.7	32.8
		III decade of August	9.5	16.5	10.7	12.1	6.3	17.7

(22 °C) than in the forest (20 °C). In the nighttime it falls below zero as a result of cooling of the open territory in the burnt-out area.

In the middle of the vegetation period (11.07–16.07 2004) the air temperature becomes warmer in burnt-out area in the nighttime (Fig. 3, *b*) and the difference of the average minimum temperatures between burnt-out areas and the forest is in the range of 0.4–0.9 °C. That is likely connected with heat loss accumulated during the day by crowns of trees and for want of the air turbulent mixing.

In the end of the vegetation period (26.08–30.08 2004) the average air temperature both in the burnt-out areas and forest becomes almost equal at the expense of the daytime temperature reduction (up to 24 °C), and the nighttime temperature does not fall below zero yet (Fig. 3, *c*). However, the temperature on burnt-out areas is lower than in the forest by 0.5–2 °C. It is explained by the turbulent heat exchange (Savvinov, 1971), which intensifies in the nighttime in the open spaces. In cloudy weather, as known (Tarabukina, Savvinov, 1990) the temperatures in burnt-out areas and in the forest become smooth according to the data of 15.07.2004 and 28.08.2004. On August 27 maximum temperature fluctuation was detected in a 10-year burnt-out area: in the daytime at 4 p. m. the highest air temperature was 24 °C and in nighttime at 5 a. m. the lowest temperature was 11.1 °C.

Fire impact on soil temperature. During the whole vegetative period the soil temperature in the burned out sites was much higher than in the forest. And the highest temperature was noted on the young burn site (Table 5 and 6).

Thus, the soil temperature in a 2-year burnt-out area at a depth of 5 cm early in the vegetation period was higher than in the forest by 5.5 °C and by 3.1 °C than in a 12-year burnt-out area (Table 6). The average temperature in the mid-vegetation period in a 1–2-year burnt-out area at the same depth was 15.8 °C, in a 10–12-year burnt-out area – 17.4 °C and in the forest – 13.1 °C (Table 5).

This sizeable warming up may be caused by ability of black surface to absorb solar rays, as reflective capacity of the dark surface of bonfire sites is much lower than the forest floor (10 and 2 %, respectively; Gavrilova, 1969).

Therewith, reduction of shading ability of tree crowns assists insolation. Maximum rising of soil temperature was observed in the middle of the vegetative period. It is known that in Central Yakutia the temperature of the open soil surface is two times higher than in the forest (Gavrilova, 1973).

Shading of the soil surface by plants increases as the burning grows over in process of succession and thus reduces penetration of direct sunlight resulting in a gradual soil temperature decrease.

According to the observation by M. K. Gavrilova (1967) made near Lake Tyungyulyu (Megino-Kangalassky ulus), which is situated in the neighborhood of our research objects (25–30 km),

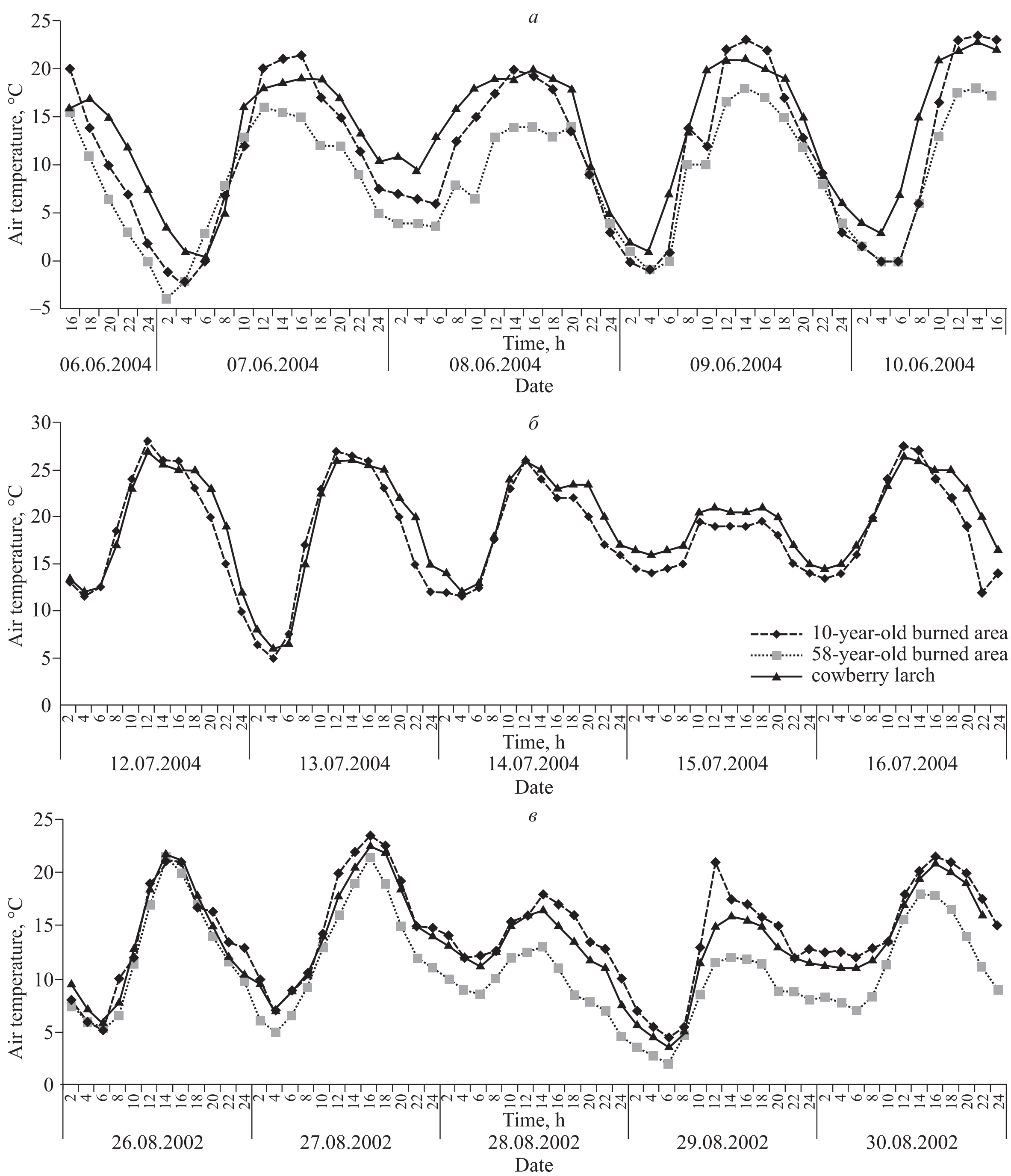

Fig. 3. Diurnal variation of the air temperature on the soil surface in burnt-out areas and the forest early in, middle and late in the vegetation period: *a* – 06.06.2004; *b* – 11.07 – 16.07.2004; *c* – 26.08 – 30.08.2002.

the soil negative temperatures at the depth of 50 cm beneath the larch remain till mid-June. Our three years' observations showed that they remain at the same depth of 50 cm (beneath the larch) till mid-July. From our point of view, it depends on the density of tree crowns in this forest site and on weather conditions of the definite year of research.

As a rule, the greatest rise of soil temperature is observed in the upper layers of soil profile in the «young» burnt-out areas. Table 6 show, that soil temperature was higher by 3.1…5.5 °C at the depth of 5 cm in the burnt-out site early in the vegetation period (early June), and by 1.4…1.7 °C at the depth of 50 cm than soil temperature under the forest canopy. The maximum temperature rise is observed in the middle of the vegetation period. The temperature difference between the burnt-out area and forest at the depth of 5 cm is 5.2… 5.6 °C, and at the depth of 50 cm –

Table 5. Average soil temperature (°C) at different depths and in different periods of vegetation

Observation time	Site	Depth, cm								
		5	10	15	20	30	40	50	80	100
II decade of July 2002	Fresh burned area	13.6	12.6	11.3	10.8	7.7	6.5	4.6	0.5	–0.2
	10-year-old burned area	16.3	15.4	14.9	14.3	13.3	12	9.8	7.3	4.1
	58-year-old burned area	14.4	13.7	12.7	11.7	11.1	8.9	7.3	2.2	0.1
	Cowberry larch	12.3	11.0	9.6	7.7	3.5	2.5	0.1	–	–
III decade of August 2002	Fresh burned area	8.5	7.6	7.2	6.9	3.5	3.2	2.5	1.0	0.1
	10-year-old burned area	12.1	10.8	10.0	9.5	8.9	8.1	6.9	4.9	3.2
	58-year-old burned area	10.2	9.5	8.5	7.7	6.5	4.8	3.6	1.2	0.1
	Cowberry larch	7.8	7.2	6.3	5.2	3.0	2.0	0.8	–	–
II decade of July 2003	11-year-old burned area	18.0	17.1	16.2	15.9	14.2	12.7	9.7	4.2	2
	59-year-old burned area	16.6	15.5	14.3	13.2	7.3	5.4	2.8	0.3	–
	Cowberry larch	14.6	12.3	11.5	8.2	6.5	4.5	0.6	–	–
III decade of August 2003	11-year-old burned area	9.1	8.6	8.4	8.4	6.6	5.7	4.7	3.3	1.7
	59-year-old burned area	9.0	8.4	7.5	6.8	3.9	2.9	2.0	1.2	–
	Cowberry larch	9.7	8.2	7.8	7.6	5.2	4.0	3.5	1.9	0.7
I decade of June 2004	2-year-old burned area	12.1	10.2	9.6	7.7	3.8	2.1	–0.2	–2.6	–
	12-year-old burned area	9.7	8.4	8.0	6.0	2.0	0.7	–0.5	–1.8	–3.3
	60- years-old burned area	7.6	6.3	4.3	3.8	–0.4	–0.9	–1.2	–2.4	–
	Cowberry larch	6.6	6.0	5.0	3.6	0.6	–0.7	–1.9	–4	–
II decade of July 2004	2-year-old burned area	18.0	17.0	14.7	12.5	10.2	8.9	7.8	5.2	0.3
	12-year-old burned area	17.6	16.8	16.8	14.6	12.1	10.1	8.4	2.8	0.6
	60-year-old burned area	13.7	11.2	10.1	10.7	4.0	2.6	0.2	–1.0	–
	Cowberry larch	12.4	12.0	10.5	9.9	5.9	3.0	0.0	–1.1	–

Table 6. Temperature difference in soils of burned out areas and nature forest (cowberry larch) at different depths, ºC

Observation time	Comparison sites	Depth, cm								
		5	10	15	20	30	40	50	80	100
I decade of June 2004	2-year-old burned area – cowberry larch	5.5	4.2	4.6	4.1	3.2	2.8	1.7	1.4	–
	12-year-old burned area –cowberry larch	3.1	2.4	3.0	2.4	1.4	1.4	1.4	2.2	–
	60-years-old burned area – cowberry larch	1.0	0.3	–0.7	0.2	–1.0	–0.2	0.7	1.6	–
II decade of July 2004	2-year-old burned area – cowberry larch	5.6	5.0	4.2	2.6	4.3	5.9	7.8	6.3	–
	12- year-old burned area – cowberry larch	5.2	4.8	6.3	4.7	6.2	7.1	8.4	3.9	–
	60- year-old burned area – cowberry larch	1.3	–0.8	–0.4	0.8	–1.9	–0.4	0.2	0.1	–
III decade of August 2004	2- year-old burned area – cowberry larch	1.9	2.1	2.3	1.5	1.3	2.5	5.0	2.9	–
	12- year-old burned area –cowberry larch	1.9	2.4	3.0	2.2	2.0	2.9	5.5	2.6	–
	60- year-old burned area – cowberry larch	1.0	0.4	–0.2	0.7	–1.4	–0.2	–0.1	–0.4	–

Table 7. Diurnal soil temperature range in uneven-aged fire-sites and in the forest (as of 7.07.2002)

Sites	Measuring depth	Soil temperature, °C, at various time of day, hours							
		8:00	11:00	14:00	17:00	20:00	23:00	2:00	5:00
Fresh-fire-site	5	11.2	12.5	13.7	13.8	12.3	12	11.4	9.6
	10	10.8	11.2	12.4	12.4	11.9	11.3	10.5	9.4
	15	10.6	10.8	11	11.2	11.1	10.9	10.3	9.7
	20	10.5	10.5	10.4	10.6	10.6	10.5	10	9.7
	30	6.8	6.8	6.9	6.9	6.5	6	5.8	5.6
	40	5.3	5.3	5.4	5.3	5	4.6	4.6	4.5
	50	2.8	3	3.4	3.3	3.1	2.9	2.8	2.7
	80	–0.1	–0.1	0	0	0	–0.2	–0.2	–0.3
	100	–0.7	–0.6	–0.4	–0.6	–0.5	–0.8	–0.7	–0.6
10-year old fire-site	5	12.7	14.0	15.0	15.7	15.2	15.8	12.5	10.8
	10	12.7	13.2	13.8	14.6	14.6	13.7	12.6	11.5
	15	12.7	13.0	13.3	14.2	14.3	13.6	12.8	11.9
	20	13.0	13.0	13.0	13.5	13.7	13.5	13.0	12.5
	30	12.5	12.5	12.3	12.4	12.4	12.4	12.3	12.2
	40	11.2	11.2	11.2	11.3	11.3	11.0	11.0	10.9
	50	9.4	9.4	9.5	9.3	9.3	8.5	8.5	8.6
	80	6.6	6.8	7.0	6.6	6.5	6.4	6.3	6.2
	100	3.0	3.5	3.8	3.2	3.3	2.8	2.8	2.8
58-year old fire-site	5	12.4	12.8	13.3	13.4	13.5	13.0	12.0	10.6
	10	12.3	12.5	12.7	12.9	13.2	12.8	11.6	11.0
	15	12.1	12.1	12.0	12.2	12.3	12.0	11.4	10.9
	20	11.3	11.2	11.1	11.1	11.2	11.1	10.7	10.3
	30	10.2	10.2	10.2	10.1	10.0	9.9	9.6	9.4
	40	8.2	8.4	8.6	8.5	8.3	7.7	7.8	7.9
	50	6.0	6.3	6.7	6.8	6.9	5.5	5.5	5.5
	80	1.1	1.3	1.5	1.5	1.5	1.3	1.2	1.2
	100	–0.9	–0.7	–0.2	–0.2	–0.3	–0.5	–0.5	–0.5
Cowberry larch (Forest)	5	8.1	9.5	10.4	10.6	9.8	9.3	7.5	6.7
	10	8.0	8.3	8.7	9.0	9.0	8.7	7.9	7.2
	15	7.1	7.1	7.2	7.6	7.6	7.6	7.0	6.5
	20	5.4	5.5	5.6	5.7	5.7	5.6	5.6	5.0
	30	2.0	2.2	2.3	2.2	1.9	1.8	1.7	1.7
	40	1.0	1.0	1.0	1.3	0.9	0.8	0.7	0.7
	50	–0.1	0.0	0.0	0.0	–0.1	–0.3	–0.3	–0.4

7.8…8.4 °C. It indicates that during the nighttime the upper layers of soil manage to use up the heat that was accumulated in the daytime whereas the lower layers fail to do it. The absence of the forest canopy and black surface of soil on a 1-year burnt-out site facilitates the greater heat emission at nighttime. In the end of the vegetation period the difference between burnt-out areas and the forest is decreasing. At the depth of 5 cm the difference is only about 1.9 °C whereas at the depth of 50 cm it is about 5.0…5.5 °C. The phenomenon of the least heat loss at nighttime is particularly evident by the end of the vegetation period.

The analysis of the variance in a daily temperature of the soil showed the greater increasing between 14.00 – 15.00, the smaller – at 5 a. m. (Table 7).

Fire impact on soil moisture. Changes in temperature and freezing conditions of soils in the post-fire periods also affect soil moisture. Taking into account that the great bulk of roots of woody and other plants is in a half-meter soil layer (Pozdnyakov, 1963*a*; Dokhunaev, 1963, 1988 etc.), soil moisture measurement was carried out up to a depth of 50 cm. Calculations showed that it increases mainly in the beginning

Table 8. Field soil moisture at different depths in the burned areas and in the control forest in 2002–2003, % of dry weight

Depth, cm	July					August				
	2002									
	The age of burned area				Forest	The age of burned area				Forest
	0–1	10–11	21–22	58–59		0–1	10–11	21–22	58–59	
5 cm	12.9	18.1	–	9.8	14.0	26.8	17.7	–	14.6	14.5
10 cm	15.9	20.1	–	7.3	15.1	20.2	17.2	–	13.0	15.7
20 cm	17.0	18.1	–	10.8	15.1	20.6	20.7	–	13.9	18.9
	2003									
5 cm	15.45	17.1	–	9.0	21.8	25	21.4	15.5	14.2	21.9
10 cm	19.3	15.5	–	9.9	17.9	21.5	19.9	12.3	14.6	15.5
20 cm	22.7	17.4	–	11.3	17.1	23.4	16.7	8.5	10.5	13.8
30 cm	23.4	19.3	–	17.1	16.0	25.4	19.1	8.6	10.4	11.5
50 cm	22.3	18.0	–	11.1	17.9	23.3	19.0	12.9	10.4	15.2

Table 9. Field soil moisture at different depths in the burned areas and in the control forest in 2004, % of dry weight

Depth, cm	June					July					August				
	The age of burned area				Forest	The age of burned area				Forest	The age of burned area				Forest
	2	12	23	60		2	12	23	60		2	12	23	60	
5cm	33.7	24	–	24.8	39.9	20.7	19.5	4.6	6.6	29.6	31.5	21.2	15.2	11.6	13.6
10 cm	33.1	21.1	–	26.2	26.4	29.0	15.2	6.2	7.3	20.2	21.2	17.2	14.8	9.4	15.5
20 cm	36.9	20.5	–	18.7	24.7	20.3	13.2	8.3	6.1	14.7	20.4	17.3	12.9	10.4	14.2
30 cm	28.7	24.9	–	16.9	26.3	20.0	13.8	11.0	9.8	14.5	20.8	14.9	12.8	12.3	13.9
50 cm	29.4	23.2	–	24.0	–	20.6	16.3	9.6	12.9	16.2	19.5	13.3	10.5	9.6	15.0

of succession: in the 1–2-year-old burned out areas – by 1.1–2.3 times, and in the 10–12-year-olds – by 1.1–1.7 times as compared to the soil moisture in the forest (Table 8, 9, Fig. 4).

And the greater excess of soil moisture on fire-sites in first year after fire to the forest occurs late in summer (August) when there is a to 2.3-time moisture increase (Table 9). This is due to rise of water from the lower water-saturated horizons of the soil with increasing thickness of the seasonally thawed layer and reduced consumption of water by transpiration to disturbed surface cover of the burning (Pozdnyakov, 1963*a*; Tarabukina, Savvinov, 1990).

Distribution of moisture in the soil profile at different depths is quite even under the forest canopy, but humidity in the upper horizons is often raised. It is explained by the ability of litter and humus horizon of the soil to retain moisture. There is over-moistened soil in the all burned areas and in the forest at the beginning of the vegetative period (the 1st decade of June). In July-August humidity becomes stable and generally slightly changes. A relative soil drying up is observed due to the consumption of water by trees and grass-shrub cover in a 20–30-cm layer in the cowberry larch and a 58–60-year-old burned area. In the middle of the vegetative period the lowest soil moisture is noted: in the fresh burned areas – due to greater evaporation from the exposed surface and in 10–12, 21–23 and 58–60-year-old burned areas – due to absorption of water by roots of larch undergrowth and grass-shrub plants, which grow rapidly especially at this time. The highest water consumption and, consequently, low soil moisture is observed in 21–23-year-old burned out sites with dominant birch-larch young growth in the cover. The birch is known as one of the species that intensively consumes soil moisture, thus partial soil drying may be associated with this property of plants.

Plant transpiration and soil moisture consumption become lower late in the vegetative season, respectively, soil moisture increases, especially in the burned out areas (Savvinov, 1971, 1976).

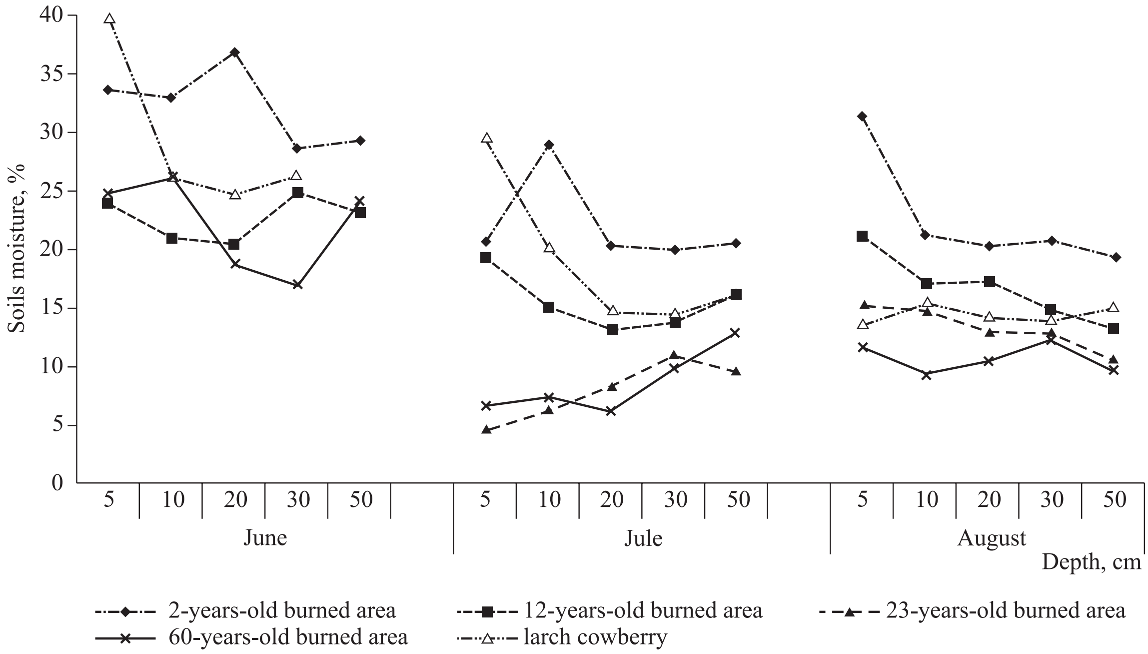

Fig. 4. Field soil moisture at different depths in the burned areas and in cowberry larch (as of 09.06.2004, 17.07.2004, and 29.08.2004).

Calculations showed that moisture of soil increases, basically, at early succession stages: 1–2-year old fire-sites – by 1.1–2.3 times, 10–12-year-old – by 1.1–1.7 times as compared to soil moisture in the forest. And soil overwatering remains on average until the middle succession stages (15–20-year-old fire-sites), after that the so-called «dehydration» of soil occurs lasting till 50 (60) years. Then at late succession stages according to self-thinning of the forest stand stabilization of soil moisture occurs.

Fire impact on permafrost conditions. Permafrost conditions of soils at the burned out areas are significantly different from those in the wooded areas. Soil in the examined recent fire sites thawed to a depth of 89 cm and under the larch forest only to a depth of 45 cm, early in June, 2002 (Fig. 5).

According to Anatoly I. Utkin (1965), the soil of the fire-sites and coupes in Central Yakutia thaws in 0.4–0.6 m deeper. According to our records, the soil in fire-sites thawed in average in 0.3–0.8 m deeper than in the forest (0.3–0.6 m in July and 0.4–0.8 in August). It is explained by the fact that in the first years favorable conditions for intensive soil warming up are created in fire-sites, that is caused by a good absorption of solar radiation by its black surface and reduction of shading ability of tree crown, in consequence of which the direct solar radiation increases (Tarabukina, Savvinov, 1990). Considering that the analyzed fire-sites have typical soil features (cryosolic taiga pale-yellow clay-loam soil – in 2, 12-year-old fire-sites and in the forest) distinctions in STL thickness are defined, mostly, by the pattern of the vegetative cover. In this case the statement made by Lev K. Pozdnyakov (1963*a*) that the vegetative cover and soil properties affect the thawing process, is partially true, because

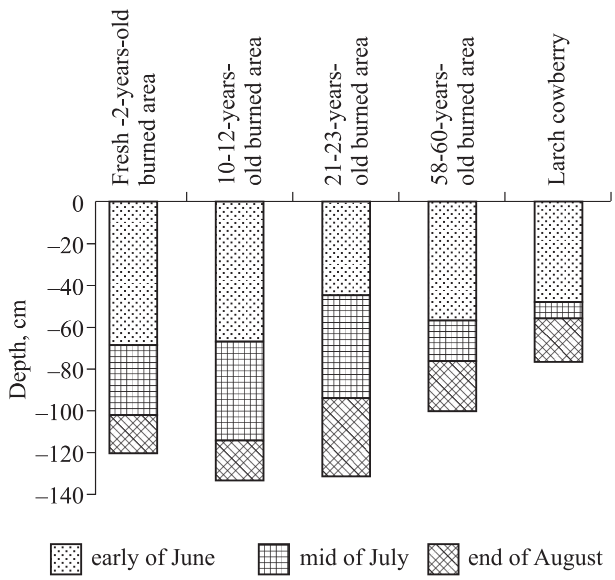

Fig. 5. Depth of seasonal thawing of the soil at different stages of succession of burned out areas and cowberry larch (averages for 2002–2004).

soil conditions in the examined fire-sites are much similar. And the STL thickness decreases in proportion to vegetation colonization of fire-sites.

The greatest thickness of the thawed layer is observed at the forbs-grasses phase in a 10–12-year-old fire site when the vegetation – mainly small grasses – does not prevent the penetration of heat into the ground, the minimum – in the larch forest, where there is the most developed heat insulating layer consisting of thick grass-shrub and moss-lichen cover and litter. The highest rate of soil thawing is typical for a young fire site (10–12 year old). In early June, the difference in the STL thickness between the burned out site and forest was 20–38 cm, late in August it reached 56–78 cm.

The analysis of a 3-year study in fire-sites allowed us to reveal quite significant dependence of the STL depth on the weather conditions, which is in a greater degree affect young fire-sites. 2004 differed from others with its cold weather conditions, lack of hot days in the summer season. For example, comparing the data of a 1–2-year-old fire-site in 2003 and 2004, we can see that in late August in 2004 the STL depth was less (118 cm) than in 2003 (135 cm), the STL depth was 2–17-cm less in the fire-sites and in forest in 2004 than in 2002–2003.

Weather conditions, and in particular, backward summer greatly affected all nature processes, including cryosolic mode of soil. Especially it is visible on the STL thickness in the beginning of the vegetative season (first decade of June) both in the forest and fire-sites.

It should be noted that vegetation regenerates almost completely within 50 years after the fire, and the thickness of permafrost, according to our observation becomes stabilized much slower. Approximately, an inverse pro- cess – soil cooling starts in 20 years after the fire starts in 20 years after the fire, i. e. stabilization of cryosolic soil behavior, whereas right after the fire there is an inverse process – degradation (thawing) of the permafrost level. According to Anatoly P. Abaimov and his co-authors (Abaimov et al., 1996; Prokushkin et al*.,* 2002) in the forests of Central Siberia it occurs in about 16 years after the fire. The difference in the depth location of STL on a 16-year-old burning and larch forest with a wild rosemary-cowberry green moss-lichen carpet is 10–15 cm, while in Central Yakutia it is approximately 55 cm (30–80 cm) in a 22-year-old fire site and cowberry larch forest, which is directly dependent on climatic differences, patterns of the permafrost spread and vegetation and fire intensity.

CONCLUSION

Thus, there always were forest fires in Central Yakutia causing direct or indirect impact on forest ecosystems. It seems practically impossible to prevent fire breaking out in the permafrost regions which are difficult to take under control by the special forest fire protection service because under the conditions of weak decomposition of plant litter and deficient mineralization of organic matter in the soil accumulation of inflammable materials in the forests of the permafrost regions is enough to be the source of forest fire emergence during the arid seasons of the year.

The research carried out showed that significant changes in microclimatic and soil conditions in the burned out areas occur in the first 10 years after the fire. And it is clearly seen especially in the young fire site. All parameters of microclimatic and soil conditions (temperature and soil moisture, STL thickness) depend on the stages of the fire site overgrowing. At the young burned site soil temperature in average increases in comparison with the forest at a depth of 5 cm in 5.2...5.6 °C, at a depth of 30 cm – in 4.3...6.2 °C, soil moisture – by 1.1–2.3 times in a 1–2-year – fire site, by 1.1–1.7 times in a 10–12-year-old one; STL thickness is 0.3–0.8 m greater in the burned areas than in the forest. There is stabilization of the modified conditions in the post-fire period in the course of succession. The process of the soil cooling and freezing begins in 20 year’s time after the fire.

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ВЛИЯНИЕ ЛЕСНЫХ ПОЖАРОВ НА МИКРОКЛИМАТИЧЕСКИЕ И ПОЧВЕННЫЕ УСЛОВИЯ ЛЕСОВ КРИОЛИТОЗОНЫ (ЯКУТИЯ, СЕВЕРО-ВОСТОЧНАЯ СИБИРЬ)

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Проанализированы данные о возникновении и частоте пожаров в лесах Центральной Якутии (Северо-Восточной России). Сделаны расчеты связи показателей горимости лесов с социально-экономическими и климатическими условиями. Выявлена тесная связь количества и плотности населения с горимостью и частотой пожаров (0.95–0.99). Не столь значительная отрицательная связь прослеживается между суммой осадков за пожароопасный период и частотой пожаров (–0.53). Приведены результаты исследования влияния пожаров на микроклиматические и почвенные условия в лесах Центральной Якутии. Проведенные исследования позволили установить, что заметные изменения микроклиматических и почвенных условий на гарях происходят в первые 10 лет после пожара. На молодых гарях температура почвы в среднем увеличивается на глубине 5 см на 5.2…5.6 °С, на глубине 30 см – на 4.3…6.2 °С; влажность почвы на 1–2-летних гарях – в 1.1–2.3 раза, на 10–12-летних – в 1.1–1.7 раза выше; мощность сезонноталого слоя на 0.3–0.8 м больше на гарях, чем в не горевшем лесу. Выявлено, что все параметры микроклиматических и почвенных условий (температура и влажность почвы, глубина сезонноталого слоя) зависят от степени зарастания гари. С течением сукцессионного времени происходит стабилизация измененных после пожаров условий, которая начинается на гарях Центральной Якутии через 20–25 лет после пожара.

Ключевые слова: *криолитозона, лесные пожары, гари, пожарища, Якутия.*

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