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ENVIRONMENTAL PROTECTION

Landscape Fires in Transbaikalia

M. D. Evdokimenko

Sukachev Institute of Forest, Siberian Branch, Russian Academy of Sciences, Krasnoyarsk, 660036 Russia

e-mail: institute_forest@ksc.krasn.ru

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Abstract—This paper presents results of wildfire studies conducted Transbaikalia over the last five decades. Station-based experimental investigations into fire hazards of vegetation accomplished at the regional forest fire stations during those years covered all altitudinal vegetation zones, representative landscape localities and forest types. Route investigations were made in different natural areas. Arial monitoring of landscape fires was used during two fire seasons. Long-term effects of fires in the Baikal Natural Area and in Central Transbaikalia were investigated. Fire regimes in vegetation complexes were analyzed and for each of them the duration of the fire hazard was determined both as the total duration for the entire season and as a continuous duration for the period of the fire maximum. Characteristics of the regimes for the altitudinal belts are provided in three versions according to precipitation amounts for a season (normal, dry and wet). It is found that forest fires occur in intensive and extreme fire regimes where most of the vegetation complexes of the region become exceptionally hazardous as compared to adjacent areas. In such a situation, there are almost no barriers to fire, except for broad rivers, lakes and mountain crests. The forest fire frequency index is high due to a predominance of light coniferous stands. A rapid spread of fires is also promoted by dry grass stands and fire-hazardous shrubs where the fire is spreading nearly as fast as the speed of wind. It was established that unmown meadows, and abandoned pastures and croplands in the outskirts of villages present the threat of devastating fires not only in forests but also in settlements. In a situation, such as the one that arose in 2015, landscape fires turn to a natural disaster with severe forest-ecological consequences. Surviving forest stands decrease in productivity and increase in self-thinning, followed by an increasing degradation caused by subsequently recurring fires. Burns undergo local deforestation or a long-lasting replacement of coniferous stands by deciduous forests. The future runoff from the burned-over areas is able to enhance pollution of Lake Baikal. It is concluded that the EMERCOM resources used to fight the latest fires in Transbaikalia showed very little promise because of being delayed. A reasonable alternative to EMERCOM would involve advanced forecasting of high risks of fire occurrence in order to rapidly fight fires with moderate expenses without letting them turning to a natural disaster.

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INTRODUCTION

According to the definition suggested by I.S. Melekhov [1], landscape fires constitute the most grandiose and destructive manifestation of a conflagration. They encompass large territories and are able to alter the state of a local landscape. As a relevant support of this suggestion, we can mention the fires of the year 2015 on the Baikal natural territory as well as the disastrous situation in the south-east of Transbaikalia where the forests were severely damaged (extensive deforestation) by the landscape fires of the years 2008 and 2012. N.P. Kurbatsky [2] included in the category of landscape fires the vegetation fires spreading over the area occupied by two or more vegetation subtypes.

Potentially, Transbaikalia differs from neighboring regions by specific natural preconditions for emergence of landscape fires: a dry climate on most of the territory, winters with little snow accompanied by a deep and long-lasting spring-summer drought with frequently recurring strong winds, and an absolute predominance of fire-hazardous light conifer stands in the forests of the region.

Analysis of forest-fire statistical data strongly suggests that large fires in Transbaikalia were a common phenomenon, especially in the most arid years. Visually, such large-scale conflagrations are indicated by extensive burnt-over areas which still retain scorched tree trunks which escaped destruction by deadfall events. A high probability for the initiation of large fires is attributed by Siberian forest pyrologists precisely to long-lasting droughts when forest fuels dry out completely across vast spaces (within landscapes and even landscape regions). It is pointed out that a natural situation, such a this, emerges in the middle of long-lasting droughts [3–5]. It is known that spring-summer droughts in Transbaikalia usually last for one or two months, and in extreme seasons even for three-four months [6]. Consequently, the risk of emergence of landscape fires in this region is very high.

The Scientific Council SB RAS on the problems of Lake Baikal, at its retreat in the Irkutsk Scientific Center (January 2019), emphasized an extremely poor state of the Baikalian forests disturbed by disastrous fires. Dark conifer forests of Southern Cisbaikalia suffered a particularly severe damage. In such a situation, results of long-term investigations into the origins of landscape fires in Transbaikalia and Cisbaikalia are of considerable current importance.

OBJECTS AND METHODS

The problem began to be studied with direct observations of the initiation and spread of landscape fires on the Vitim Plateau as well as in the Selenga middle mountains, in the process of regular aerial surveillance of the territory of these natural districts. Over the course of the fire-hazardous seasons of 1964 and 1965, distinguished by a high fire frequency index, the author of this paper studied a comprehensive picture of the evolution of fires, from their initiation to their end. According to visual aerial monitoring data, the pyrogenic anomaly was experienced by about 2–3% of the aforementioned territory in 1964, and by about 7–8% in 1965.

We carried out the experimental investigations into the process of fire maturing of representative areas for all altitudinal-belt complexes (ABC) of vegetation within the Lake Baikal drainage basin in the 1970s. The objects for station-based pyrological observations (the trial areas 0.3–0.8 ha in size) encompass all altitudinal belts and landscape localities on the characteristic mountain ranges (Malkhanski and Khamar-Daban. The route investigations were made mainly on the territory of the most fire-prone subtaiga-forest-steppe and light conifer taiga belts in the Selenga middle mountains, including the valleys of the main tributaries of the Selenga river (Chikoi, Khilok and Uda) as well as in Central and Northern Cisbaikalia (Ingoda river basin), and in the north of Transbaikalia (Chara depression).

In selecting the objects for expedition-based studies, use was made of data on forest organization and forest-fire statistical data on the distribution of particular territories as well as on their actual fire-prone characteristics. In general, the objects for studies (41 station-based studies, and 45 route investigations) quite adequately reflect the variation in fire hazard for characteristic landscape stows and localities in Transbaikalia.

Station-based investigations into forest-ecological consequences of large forest fires were made during the 1970s–1980s in Southern Cisbaikalia (Khamar-Daban Range), and in Central Transbaikalia (Yablonevoi and Cherskii Ranges). The route investigations into pyrogenic successions were made from 1983 to 2016 in the Selenga middle mountains, Khentei-Chikoi Highlands, the Vitim Plateau, in the Barguzin depression as well as on the territory of the Stanovoi Highlands (the valleys of the Upper Angara, Muya and Chara rivers). The main objects for study were represented by pyrogenic pine and larch forests belonging largely to the rhododendron group of forest types, of widespread occurrence throughout the region.

RESULTS AND DISCUSSION

A fairly complete picture has been obtained to date as regards the potential fire hazard of vegetation on the territory of Transbaikalia, which is differentiated with respect to altitudinal belts, depending on the phenological status and meteorological situation. This data can be used to objectively determine the pyrological regimes in particular areas: from facies (forest types) and stows to localities and landscapes [7, 8].

According to the definition provided by V.V. Furyaev [9], the pyrological regime of natural territorial complexes characterizes the mutually conditioned state of ecological regimes and dynamics of forests with the intensity and consequences of fires. In his case study of the landscape of the Kas-Yenisei erosion plane, he developed the scale of pyrological regimes, with the main indicator represented by an actual long-term recurrence of fires: frequent, medium, rare and very rare. Special investigations determined a close relationship of the fire recurrence with the hydrological regime of corresponding facies and stows (waterlogging and water table).

In our investigations into the pyrological regimes with reference to the mountain landscapes which are distinguished by the uniqueness of the natural conditions, the main indicators included the potential fire hazard of the particular categories (ABC and forest types) as well as the intensity and ecological consequences of fires [7, 10]. By analogy with V.V.

Furyaev's classification, four gradations of the pyrological regime were established but their names focusing on a corresponding ecological situation: safe, moderate, intense and extreme (Table 1). A study was made of s dependence of the pyrological regimes from ABC on the meteorological situation. The analysis provided the necessary assessments of the size of the fire-hazardous territory as well as the eventual duration of the fire-hazardous conditions both total for a year and continuous during the spring-summer fire maximum.

Typical for each ABC are its dominants in vegetation cover and its characteristic combinations. The wide latitudinal range of atmospheric humidification within the Baikal drainage basin is responsible for the regular transitions from some vegetation complexes to others [11] and, hence, for their pyrological regimes [12] (Table 2).

The zone of insufficient humidity, along the valleys of large rivers and in the low mountains, is dominated by arid steppe complexes with forest-steppe and subtaiga which regularly experience an intense and an extreme regime. The percentage of forest land makes up a mere 20–40%, and the composition of forest is dominated by Scots pine. The zone of moderate humidity, on cold (with frozen ground) soils is dominated by taiga larch forests. In an ordinary meteorological situation, the zone is characterized largely by an intense regime.

In the wet belts (higher than 1200 m above the sea level) there occur dark conifer complexes with a moderate pyrological regime. Vegetation forming and surrounding the upper timber-line, with a characteristic excessive humidity and a shortage of heat, is represented by compound subalpine complexes characterized by a safe regime.

The overall length of a fire-hazardous season on an individual territory depends on the duration of the snow-free period which in the subalpine-subgoletz belt is twice as short as that on forest-steppe and subtaiga spaces. The differences in snow storage are even more contrasting. Precipitation amounts for a cold period of a year in wet belts with dark conifer stands and in subalpine sparse larch forests with dwarf Siberian pine are by a factor of 2–4 larger when compared with forest-steppe and subtaiga localities.

Incidentally, we should not overemphasize the practical significance of the altitudinal variation of precipitation amounts (including snow cover of the

Table 1. Pyrological regimes of vegetation in Transbaikalia

Regimes	Potential fire hazard of the ABC territory, %	Duration of the fire-hazardous state, days	
		total for a year	maximum continuous
Safe	< 10	< 40	< 10
Moderate	11–30	41–70	11–20
Intense	31–70	71–100	21–30
Extreme	> 70	101–140	31–70

Table 2. Pyrological regimes of ABC within the Baikal drainage basin (spring-autumn period)

Altitudinal-belt complex, prevailing vegetation	Pyrological regime		
	regular seasons	dry seasons	wet seasons
Meadow-steppe ABC, mountain steppe	Extreme	Extreme	Intense
Subtaiga-forest-steppe ABC, forb and rhododendron pine forests	Intense	Extreme	Moderate
Light conifer taiga BC, pine-larch stands with true moss-subshrub cover, yernik vegetation	Intense	Extreme	Moderate
Siberian stone pine taiga ABC, true moss-cowberries Siberian stone pine forests	Moderate	Intense	Safe
Siberian stone pine-fir ABC, bilberries-true moss Siberian stone pine and fir forests	Moderate	Intense	Safe
Subalpine subgoletz ABC, conifer open woodland and dwarf Siberian pine forests	Safe	Moderate	Safe

upper belts) for the potential fire-hazard of vegetation cover for the region as a whole. It is known that within the Lake Baikal drainage basin the proportion of the subalpine-subgoletz ABC accounts for a mere 4%, and the Siberian stone pine-fir belt occupies only about 2% of the total area. On the other hand, the meadow-steppe and subtaiga-forest-steppe complexes occupy 41% and the neighboring light conifer taiga forests 35% of the Baikal natural territory [11]. In essence, it is these categories, as the largest in size, that determine the general status of vegetation cover in the region and, hence, the natural fire-hazard.

Pyrologically, Transbaikalia exhibits a particularly unfavorable combination of xerophytic steppe vegetation with highly fire-hazardous light conifer forests growing on large spaces in conditions of an arid climate. The annual precipitation amount in the light conifer taiga constitutes a mere 280–330 mm, and in the subtaiga and forest-steppe it is even smaller. Furthermore, he contribution from snow makes up a mere 5–10 % of the annual amount; therefore, snow cover disappears earlier, largely evaporating in a dry air environment, usually as early s March, within a mere one or two weeks, with the establishment of positive values of daytime air temperature, with its known low humidity at that time. As a result, the ground layer of fuels is almost not moistened by meltwater, especially in insolated localities, because of its paucity or total absence.

An exceptionally snow-deficient winter on the ABC (meadow-steppe, subtaiga-forest-steppe and light conifer taiga) dominating the territory is accompanied, as pointed out above, by a deep and long-lasting spring-summer drought, as indicated by data summarized in Table 3. Throughout the entire springtime there are usually no atmospheric precipitation capable of at least slightly attenuate the natural fire hazard across the huge space with the aforementioned dry ABC. According to data from the hydro-meteorological service [6], during March-April the precipitation amount of more than 1 mm occurs not more frequently than once a ten-day period, and there are no precipitation at all, exceeding 5 mm which are able to eliminate the fire hazard, at least for a short period (for a mere 1–2 days). This is likely to occur only once at the end of spring, in the last ten-day period of May, and later, by mid-June. Such rainfall occurs once or twice on the territory of the meadow-steppe and subtaiga-forest-steppe ABC, and in the light conifer taiga ABC two or three times, which triggers an active growing period of grass plants. And in especially dry seasons, a drought lasts till the end of June and, later, with short interruptions, it extends throughout July through August. In the disastrous 2015 season, the drought also continued in September.

In conformity with the aridity in the region, here objectively exist localities with an especially high risk of occurrence of large (landscape) fires. They include primarily meadow-steppe spaces with dry grass which can burn beginning in early spring. The earliest meadow-steppe fires, as precursors of the eventual fire disaster, usually emerge in early-mid-March. The meadow-steppe localities, the adjacent insolated sites of light conifer stands, with no snow already, become fire-hazardous, almost simultaneously with the meadow-steppe localities. Also, the low air humidity and strong spring winds promote a rapid spread of the incipient fires over large areas, in accordance with the extreme pyrological regime.

Table 3. Regime of atmospheric precipitation for ABC during the spring-summer fire maximum (in regular seasons)

ABC	Meteostation, abs. height (m)	Precipitation for months, mm			
		March	April	May	June
Meadow-steppe	Barguzin, 489	3	7	12	27
	Novo-Selenginsk, 544	1	4	11	36
Subtaiga-forest-steppe	Ulan-Ude, 510	2	4	12	36
	Khorinsk, 665	3	5	14	27
Light conifer taiga	Kizhinga, 707	4	7	16	32
	Cheremkhovo, 880	3	9	21	49
Siberian stone pine taiga	Yamarovka, 985	7	17	30	66
Siberian stone pine-fir	Verkhnyaya Mishikha, 1280	15	19	39	87
Subalpine-subgoletz	Averaged data from the weather service	30–40	40–60	80–110	130–200

The swiftness of the spread and the strain of the fire-hazardous state in meadow-steppe localities and in light conifer forests are caused not only by a shortage of atmospheric precipitation. It is known that the evaporative capacity of moisture at that time exceeds its current input by a factor of 5–10. The probability of days with a relative air humidity below 30% in subtaiga forests is 0.60–0.70 throughout May. In June, the gap between humidification and evaporation of moisture decreases by nearly one half. A fire-safe situation occurs in ordinary seasons in July only, when atmospheric precipitation exceeds considerably the evaporative capacity of moisture [6].

The climatic situation on the territory of the subtaiga-forest-steppe ABC differs little from the aforementioned characteristics typical for the meadow-steppe ABC. The steppe is followed by an escalation of fire-prone areas in the subtaiga. Initially, this occurs in pine stands with disappearing snow in slightly elevated localities, and beginning in April all pine stands in the subtaiga are able to burn. By mid-April hot spots can also emerge in larch stands of the subtaiga, and one week later the fire hazard spreads over most of the light conifer taiga.

An extremely unfavorable feature in the natural fire hazard in the region is an exceptional pyrological monotony across most of the territory(within the boundaries of the three ABC under consideration), with a relatively low (about 3000 units) value of the integrated meteorological index, in accordance with which the activity of the forest fire control service is regulated. Notice that in the spring this critical threshold of a so-called “fire maximum” is usually recorded at the end of the second week of a dry weather. On the other hand, the time interval without any substantial atmospheric precipitation even in seasons with a regular meteorological situation is significantly larger, not to mention the especially dry seasons. Hence, the natural preconditions for emergence of landscape fires in Transbaikalia begin to operate early and last very long.

Note that the pyrological monotony can spread at a time over two-thirds of the total area. In such an expanse in a similar situation there are almost no barriers to fire except for large lakes, broad rivers and still wet crests on the mountain ridges, with dark conifer forests and subalpine vegetation which are isolated and do not form any closed network. Furthermore, the channels of small rivers and brooks surrounded along their valleys by meadows or shrub vegetation (yerniks) are unable to inhibit the spread of fires, because such vegetation per se presents a high fire hazard in the spring. Accordingly, the intensity of burning is enhanced dramatically in such localities, and, with high gust of wind, fire easily overcomes the narrow water barriers, snow patches and aufeis.

The ground layer of fuels in the forest across the entire territory of the forest-steppe and subtaiga is represented mostly by active components which can burn from the first days of a dry weather after the disappearance of snow cover or after rainfall. The main burning agents are flammable plant litter consisting of needles, cones and small dead branches, dead grass and dry debris layer. Thin particles of litter and dry grass lying in the form of a loose freely ventilated layer rapidly evaporate moisture contained in them. In open places and in sparse stands, dead grass and plant litter can dry out to a flammable state on the first day after scarce spring precipitation, literally within a few hours. And fire moves on a dry grass several times faster than on the other fuels.

Steppe fires spread with wind speed, presenting a fatal threat to settlements whose edges are overgrown with weeds and covered with litter. On the forest territory they bring the threat primarily to forb pine stands whose edges are particularly vulnerable to fire. Subsequent to these categories, burning can spontaneously spread along the steep southern slopes to mountain-stone pine stands. Such a situation in the case of controlled burning of dry grass is possible in the spring during 1–2 days, after the lighting of fire. After that, within 2–3 days, fire can affect the other types of pine forests (forb-rhododendron, cowberries-forb) and, then, subtaiga larch forests (Fig. 1).

Fire-prone maturity of stands in the light conifer taiga ABC is more spread over time (when compared with the forest-steppe and subtaiga, about twice). There, rhododendron-cowberries pine stands turn into a fire-hazardous state within 3–4 days, and true moss pine stands only within 6–10 days of a dry weather. In rhododendron-cowberries larch stands, and in birch stands (similar in the character of soil cover), a critical duration of a dry weather is 4–6 days. But 10–15 days are necessary for fire-prone maturing of ledum and true moss larch forests.

The fire hazard of ABC with dark conifer forests sets in substantially later, i. e. with the disappearance of a relatively thick (for Transbaikalia) snow cover. Thus, in the taiga and Siberian stone pine-fir belts, snowbreak extends throughout May, while in the subalpine-subgoletz ABC with the occurrence of dwarf Siberian pine vegetation, snow disappears by mid-June only. What is more, in this belt, as a result of high humidity of a thick moss cover, fire-prone maturing proceeds

Fig. 1. Formation process of a landscape fire (spring-autumn variant).
a – steppe fire; *b* – fire in subtaiga; *c* – fire in light conifer taiga; *d* – general view of a mature landscape fire (according to material from the Siberian Forest Fire Center for 2015).

slowly and is regularly interrupted by abundant atmospheric precipitation, as is shown in Table 3.

Landscape fires on the territory of the upper belts occur only rarely, during long-lasting summer-autumn droughts. They lead to losses of especially important (for the Baikal natural complex) Siberian stone pine forests, whereas in the subalpine belt the upper timberline comes lower after the burning of localities with sparse larch forests and dwarf Siberian pine stands.

Such is the sequence of the distribution of fire-hazardous conditions according to representative categories (localities, altitudinal belts, and forest formations and types) in Transbaikalia. The pyrological background of natural districts and landscape localities varies with the cenotic structure of landscapes.

In the light coniferous taiga ABC, in addition to meadow localities, fire-prone vegetation usually includes shrub birch trees (yerniks) which tightly penetrate the taiga landscapes along the valleys of braided intermontane depressions (pad's). According to the degree of fire hazard in the spring, taiga meadows with yerniks are only slightly exceeded by the adjacent background of steppe and forest-steppe landscapes. Furthermore, on the vast Vitim Plateau, for example, they occupy very large areas. On the general purpose map of vegetation of Transbaikalia [13], the Eastern-Vitim area of the Baikal-Dzhugdzhur natural region is highlighted as the area dominated by yernik Angaride larch forests. In interfluves and in valleys, they include yerniks and sedge bogs.

It is mainly on this territory that the author of this paper carried out an aerial monitoring of the actual pyrological situation over the course of two complete and relatively tense fire-hazardous seasons of 1964–1965. As a consequence of long-lasting droughts (extreme pyrological regime) there occurred long-lasting landscape fires. At that time, such fires were impossible to suppress in hard-of-access localities, given the poor technical capabilities of the forest protection service.

The Vitim Plateau is also distinguished by continuous permafrost. In places with excessive ground moistening (along the lowest sites) there occur swamped meadows with sedges. These localities often abound in hummocks 30–60 cm in height, and permafrost begins at a depth of about half a meter [14]. Within two or three days of a dry weather, grass-shrub vegetation as early as the very beginning of the fire-hazardous season dries off to such an extent that it can burn in these localities across considerable areas measuring several thousands of hectares.

In the same area, using helicopter post-monitoring of landscape post-fire sites we visually studied he mechanism of long-lasting hot-spot burning (smoldering) of hummocky meadows by digging out the peatified turf to a depth of 20–30 cm. Usually, such probing is disregarded by the forest protection service. From general macro-indicators of the absence of flame burning, it is possible to verify localization or even suppression of the fire, whereas in hummocky areas with peaty turf burning in the flameless phase can last for weeks and months, and new hot spots of ordinary fires can emerge at the contact with fire-mature areas at the edge of forest.

The general purpose map of vegetation of Transbaikalia [13] suggests the conclusion about the typicality of the Angaride Daurian larch forests encompassing completely the Vitim Plateau with a large number of swamped larch stands with the undergrowth of yerniks alternating with yernik mono-vegetation and grass-moss bogs. The soil cover of the bogs is characterized by the existence of hummocks and thick peaty turfs [15] which are due to permafrost as well as to low air temperatures. Peaty soils also occur there. The thickness of peaty turf is 20–35 cm. The hummocks are 30–50 cm in height.

Spring fires on the Vitim Plateau, especially in yerniks across a large and pyrologically uniform territory of a so-called "basalt plateau", are distinguished by a high speed of fire spreading. Flame eddies during strong winds tear and blow away tops of grasses and shrubs along the direction of fire spreading. New hot spots emerge in front of its leading edge. Within a few hours the fire encompasses a huge area turning into a natural disaster (landscape fire). Such fires are difficult to suppress even in cases where the fire edge can be stopped. The matter is that hummocks and grass turf continue to burn even after their surface has burnt over. Furthermore, peat can burn even with high absolute humidity, up to 400–500% [16]. This is, in fact, confirmed by the fact that peat fires occur on the bogs on the southern shores of Lake Baikal. Such fires can last for months without stopping even in the winter until peat burns out completely.

In accordance with the thickness of turf and peat, smoldering on the objects for our studies (Vitim Plateau) lasted for 1–3 months, which is not long when compared with peat fires in the European part of Russia. But in Transbaikalia this would entail renewal of flame burning in a multi-scale for across a vast territory with the inevitable occurrence of landscape fires. Noteworthy in this context is the challenging situation with springtime burning treatment of dead grass litter on meadows on a dry soil. It is usually thought that to carry out this measure immediately after the disappearance of snow cover implies a sufficient condition for the prevention of fires in forest stands, with some snow still remaining under their canopy. Unfortunately, in extreme seasons when a thin (and fragmentary) snow cover scarcely overlays an almost dry ground layer of fuels, there remain after such "agricultural burning treatment" numerous and slightly conspicuous micro-hot spots of flameless burning. The taiga territories in the zone of such burning treatment represent a fire-prone "mine field". The inevitable consequences of "mining" are the chaotic ignition events of forests.

The exclusiveness of the situation on the territory with permafrost also implies that the soil remains frozen till the end of May. It is not possible to plow the land, and this is necessary for producing barriers to the spread of fire (mineralized strips and furrows).

Significant areas east of the Vitim river are occupied by sparse larch forests with the undergrowth of yerniks which, when approaching the Olekma river basin, turn into larch mari. Yernik mono-vegetation also grows there, as well as cottongrass-sedge bogs with hummocky marshes, as is the case in the south of the Vitim Plateau [17]. Before the beginning of the growing period these categories are highly fire-hazardous.

The area west of the Vitim Plateau is dominated by ledum larch stands on drained earth material, and of widespread occurrence on Baikal's shores are larch forests with the fire-hazardous undergrowth of Daurian rhododendron [13]. These are also typical for forested areas in the southern and central regions of Transbaikalia [18]. Hence it follows that the intensity of Transbaikalian fires is high.

In northern Transbaikalia with mountain-tundra and goletz formations on mountain ridges, the forest-pyrological uniqueness on relatively well developed territories is determined by xerophytes pine and larch-pine forests of the pine-wood type growing along the valleys of the Upper Angara, Muya and Chara rivers [13]. In these categories, the fire-hazardous season begins 2–3 weeks later than in the south and in the center of the region. But according to the maturing rates of the main forest types and treeless localities, they are similar to the pattern common to the region, including according to the degree of pyrological monotony of the territory. Hence, the risk of emergence of large (landscape) fires is high.

Xerophyte larch types of larch stands in the landscapes of the Selenga middle mountains and Central Transbaikalia expand considerably the unfavorable pyrological background consisting of pine stands.

It follows from the aforementioned pyrological characteristic of vegetation cover that the natural preconditions for the occurrence of landscape fires exist throughout the entire territory of the region.

In especially dry seasons, landscape fires turn into a fire disaster (Fig. 2). In 2003, and, specifically, in 2015, an extreme pyrological regime lasted as long as the end of summer. In the latter case, the fire disaster that affected the Baikal natural territory ended only in September after abundant and long-lasting rainfalls. Incidentally, there remained active hot points of the disaster in the form of peat fires.

To date the emergence of disastrous situations with natural fires is caused by primitive economic preconditions: unmown meadows, abandoned pastures and croplands at the edge of settlements, desolation of settlements themselves, and general regress of the fire control infrastructure on the forest territory. The traditional lifestyle of villagers has been lost; it was ecologically balanced and rational in terms of the fire prevention. While in the past there was nothing that could burn in overgrazed pastures and mown meadows, nowadays they are continuously covered by dry grass with weeds. In a windy weather (and strong winds occur frequently in the spring), fire spreads rapidly over ownerless territories. In a few hours it reaches nearby forest stands, and before that it can destroy completely the settlements themselves, in the vicinities of which the fire has its origin.

The problems of today's situation are also due to delays in involving stand-by arrangements which turned out insufficiently effective. Thus, air tankers in the event of considerable haze pollution cannot dump water accurately enough on the fire front, i. e. are almost always useless. An alternative approach would imply preventing such situations by forecasting in advance a high risk of occurrence of disastrous landscape fires. Institute of Forest SB RAS has the necessary research findings for developing an appropriate technology of forecasting and monitoring model areas (localities) [19]. A decrease of the amount of autumn-winter precipitation by more than 15–20% of the normal can be used as a reliable precursor of an extreme season. And the ground vegetation cover of dry fuels, which resides in a dry state beginning in autumn, is almost scarcely dusted with snow, and in the forest-steppe and in the taiga this occurs in some places only. Such a snow cover in a dry air environment disappears as early as the middle or beginning of March. The absence of a noticeable amount of meltwater in forest is obvious evidence for an extreme state of the fire situation in a next season.

Extensive landscape fires leave behind a chaotic mosaic pattern of areas of damaged and dead stands. Later, in the process of post-fire forest regeneration there arises a complicated combination of unevenly aged groups of stands and separated stands which are intermittently modified by recurring fires. In the case of severe damage of forest stands, the recovery of their pre-fire degree of stocking and growing stock takes a long time, while recurring fires give rise to pyrogenic

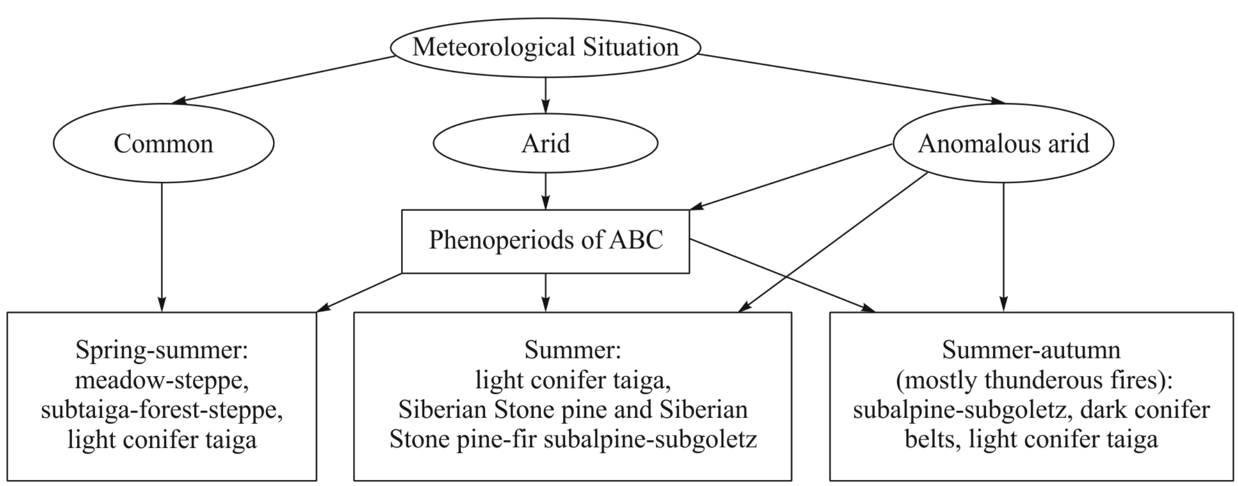

Fig. 2. Schematic map of landscape fires for altitudinal-belt complexes depending on weather conditions and on the phenoperiod.

digression with an inevitable loss of the economic and ecological significance of stands. Local deforestation occurs in dry localities.

The pyrogenic history of the forests in Northern Cisbaikalia was the subject for studies carried out by V.N. Sukachev and G.I. Poplavskaya [20] and, later, complemented by the efforts made by a comprehensive expedition under the guidance of V.N. Sukachev [21, 22]. The consequences of the landscape fires that occurred a century ago indicated largely a disastrous disturbance to the entire profile of the forest belt, i. e. fire encompassed the territory of whole landscapes. Fires destroyed the main components of the dark coniferous taiga: Siberian stone pine, fir and spruce. Earlier, these assemblages were of more widespread occurrence there. A characteristic feature of the pine stands was a comparatively low (for Siberia) critical age (160–200 years) of forest stands [22]. The upper timber-line lay on frequent occasions lower because of fires which destroy larch stands with underwood consisting of dwarf Siberian pine. Even more fatal and irreversible losses were observed amidst monostands of dwarf Siberian pine [21].

The humid localities of the Baikal depression are characterized by a pyrogenic succession of coniferous species by deciduous species. Thus, as a result of a series of fires after the construction of Transsib, the Siberian stone pine forests growing along the southern shores of Lake Baikal were replaced for a long time period by birch and aspen forests.

Pyrogenic disturbances to the hydrothermal regime of soils fatally exacerbate the limiting role of humidification which is characteristic for the productive process of pine stands in Transbaikalia. The most clearly pronounced and long-lasting are the losses of stand growth after intense fires on steep slopes. An integral criterion of silvicultural consequences caused by pyrogenic disturbances to the forest vegetation environment is the decreased quality class of pine stands. Landscape fires are followed by an intensification of the overland runoff, which disturbs the hydrological regime of rivers and increases the suspended sediment concentration.

In 2003, on the Baikal natural territory the losses of forests from 10 to 20% occurred in the Baikal'skii, Pribaikal'skii, Gusinoozerskii, Zaigraevskii, Kiszhiginskii, Kudunskii, Khorinskii, Badinskii, Krasnochikoiskii, Beklemishevskii and other forestries. Such devastating landscape fires affected the forested areas having a well-known biosphere significance.

Fig. 3 presents the map of hot spots of fires that occurred in 2015. Data on the total burned-over area are

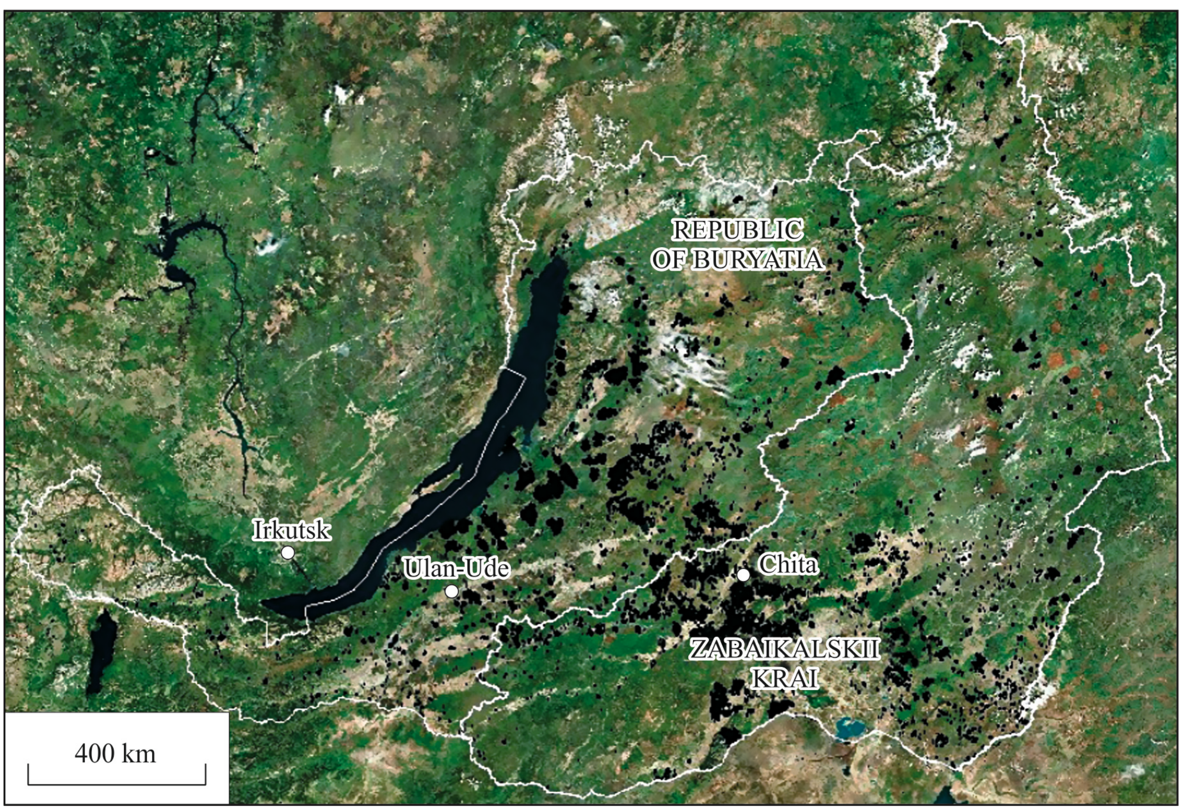

Fig. 3. Hot points of forest fires in Transbaikalia from April to August 2015 (according to data from the Siberian Forest Fire Center).

contradictory. According to a consolidated assessment, the fires affected forested areas on the territory of about 2 million hectares. The most severe fires occurred in the Selenga middle mountains and in most of Eastern Cisbaikalia. The taiga and subalpine localities of the Ikatskii mountain range were disturbed considerably by fire. A disastrous situation with severe consequences was observed in the central and southern areas of Zabaikalskii krai.

Losses of the Baikalian forests caused by landscape fires in 2015 were most significant over the last 100 years (see Fig. 3); they exceed by a factor of 3 the damage from fire in 2003. Hence, there are inevitable severe ecological consequences for Lake Baikal from pollution by the runoff from vast burned-over territories.

A.K. Tulokhonov and A.N. Beshentsev [23] attribute the low effectiveness of the forest fire protection to the existing legal collisions. Responsibility for the forest protection rests with the federal subjects of Russia without any adequate funding. Hence, it is important to develop new technologies for the organization of forest protection efforts. Thus, V.M. Plyusnin et al. [24] point out that unmanned flying vehicles have considerable promise, which is certainly important for quick detection of natural fires and their prompt suppression, with moderate expenditures involved.

CONCLUSIONS

Landscape fires in Transbaikalia usually occur in the period from spring to mid-summer under intense and extreme pyrological regimes that dominate in vegetation complexes across vast territories during long-lasting and deep droughts which set in after a specific Transbaikalian snow-deficient spell.

Results of long-term investigations of natural fires were used to obtain a differentiated (with respect to altitudinal belts) pattern of pyrological regimes in corresponding vegetation complexes. Four gradations (levels) of the regime were identified: safe, moderate and extreme. The names reflect the degree of fire hazard and probable ecological consequences of fires. For each gradation the duration of the fire-hazardous conditions was determined: both the total duration for the entire season and the continuous duration for the period of the “fire maximum”. Accordingly, on this basis it is possible to assess the risk of occurrence of landscape fires as well as the character of forest-ecological consequences for altitudinal belts and particular localities.

In the springtime, when the value of the integrated meteorological index exceeds 3000 units (it is usually recorded two weeks after a dry weather), there occurs an exceptional (in comparison with neighboring territories) pyrological monotony o prevailing vegetation complexes. About two-thirds of the region’s territory find themselves in a fire-hazardous state simultaneously.

Even in a regular meteorological situation corresponding to a long-term normal, the pyrological monotony of vegetation complexes implies a high risk of landscape fire occurrence as such. Spontaneous forest fires can spread over the territory of two or three altitudinal belts. But their magnitude and physical parameters under controlled circumstances compare with the capability and technical capacities of the fire control services for suppression and localization of fires. This implies a sufficient normative number of skilled personnel, technical sophistication and proper responsiveness.

In a situation, such as occurred in 2003 and, especially, in 2015, when an extreme pyrological regime in most of the Baikal region lasted from spring to autumn, there is hardly any hope for the internal possibilities, because landscape fires turn into a natural disaster with the most severe ecological consequences for the Baikal natural territory, including pollution of Lake Baikal by the runoff from extensive burns and burnt wood. In such cases, there is an obvious need to attract appropriate State reserves. At present, however, a problem situation, a delay, recurs, as was the case before. Hence, there arises a need for forecasting in advance an extraordinary natural fire hazard in order to make manoeuvring with reserve efforts forestalling and effective. Institute of Forest SB RAS has the necessary research results for developing an appropriate technology of forecasting and monitoring the fire situation in representative model areas.

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