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IMPACTS OF WILDFIRE LOW-SEVERITY ON SOIL PROPERTIES IN SEMIARID FOREST ECOSYSTEMS OF WESTERN TRANSBAIKALIA

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Abstract. Impacts of wildfire low-severity on soil properties on 2 sampling plots of the dry pine forest in Western Transbaikalia are studied. Low-severity surface fires in the studied pine forests have a positive effect, since they activate the processes of litter decomposition and further dissolution of organic substances that provide soil and plants with accessible elements. Pyrogenic morphological features persist for a long period after a fire. These include the presence of black carbonaceous subhorizon at a depth of 14-14.5 cm, ocher mottles along the roots of burnt trees. These features are shown in the increased content of iron in the Tamm extract and exchangeable bases. This creates conditions for the fixation of humus associated

with both calcium and iron hydroxides. Also there is a slight increase in the content of the clay fraction. Two years after the fire the properties of the soil change significantly. Eleven years after the fire, most soil properties are quickly restored to pre-fire levels.
Keywords: semiarid ecosystems, wildfire low-severity, forest litter, soil properties.

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Introduction

The area of the Selenga Mountains forest-steppe landscapes in Western Transbaikalia is characterized by the alternation of mountain ranges and intermountain valleys, where the ecosystems are represented by dry pine forests with Scots pine. The distinguishing feature of these forests is the steppization of the grass cover make them particularly vulnerable to fires.

Intermountain valleys are confined to the gentle slopes of piedmont plume ridges, floodplain and floodplain terraces of river valleys.

At present, there is an increase of aridization in the forest-steppe ecosystems of Western Transbaikalia, associated with warming of climate [Kulikov et al., 2014]. Frequency of wildfires connected to atmospheric droughts play an important role in the transformation of soil and vegetation cover and is predicted to increase in the future because of climate change [Flannigan et al., 2006].

Wildfires alter soil morphological, physical and chemical properties depending on the fire severity and depend on many factors including fire type, severity, intensity, frequency, climatic conditions, topography, plant composition, and the time elapsed since fire occurrence [Arocena & Opio, 2003; Badía & Martí, 2003; Zavala et al., 2014].

Wildfires in semiarid landscapes of Western Transbaikalia are a major environmental concern where climatic conditions (dry and hot summers and cold winters) are favorable for ignition. In addition, human activities play an important role in fire occurrence. At present, has been an increase in the number of wildfires and total burnt area of territories.

The objective of this paper is to exsamine the impact of wildfire low-severity on morphological and physicochemical properties in forest soils in semi-arid ecosystems of Western Transbaikalia.

Material and methods

The study site (51°44'N, 107°34'E) is located near Lower Sayantui to 6 km from Ulan-Ude city (spurs of the northern macroslope of the Tsagan-Daban ridge of the Selenga Mountains, Western Transbaikalia (Figure). The study area has a bias to the northwest and borders the vast valley of the Selenga River which determines the free penetration of prevailing winds.

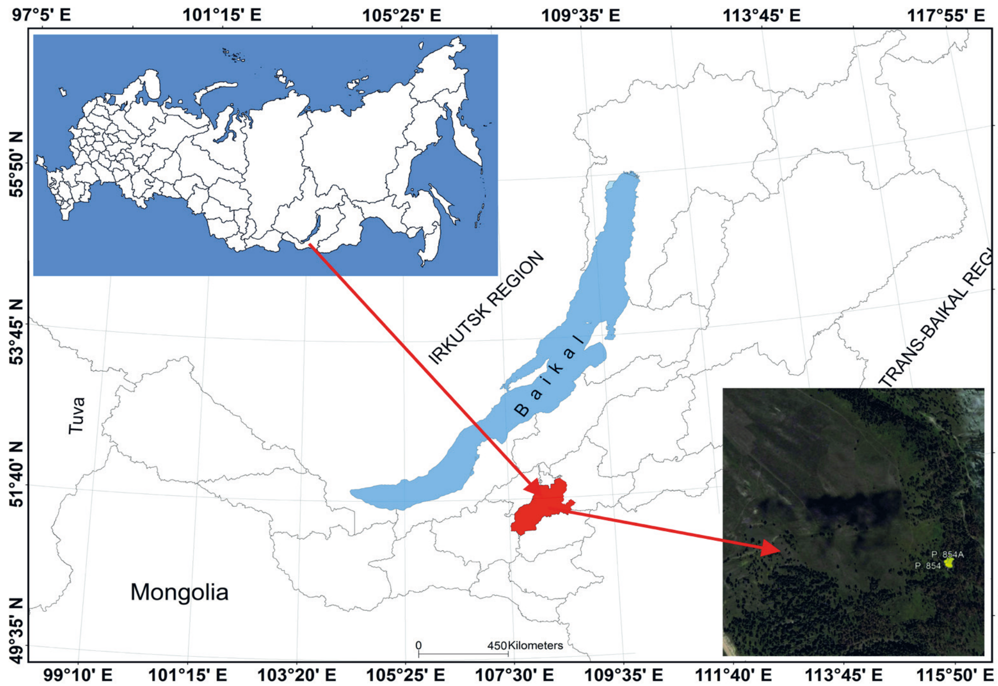

Fig. Location map of the study sites

The Selenga Mountains district in Western Transbaikalia is located within the transition climatic zone between a cool continental climate (Dwc) and a cold semiarid climate (Bsk) (updated world map of the Köppen–Geiger climate classification; Peel et al., 2007). In winter with the establishment of anticyclone atmospheric circulation, strong cooling and desiccation of soils take place. Intermountain depressions are characterized by the development of winter temperature inversions, where a more severe microclimate is established. In summer in the basins the air is much warmer than on the adjacent slopes and watersheds. Annual precipitation does not exceed 250 mm.

The anthropogenic impact on the surveyed area consists of ploughing the bottoms of wide valleys and gentle slopes, subsequently leading to drift of sand material and the formation of Eutric Arenosols, and often repeated forest fires. According to the soil-ecological zoning of the basin of Lake Baikal, Eutric Arenosols are formed on the pine forest terraces of large river systems and the lower parts of the slopes of mountain ranges [Ubugunov et al., 2019]. Parent material consists of loamy sand deposits underlain by sands.

Soil features were described according to Guidelines for Soil Description[1]. Physicochemical properties were carried out by conventional methods [Vorobyova, 2006]. Soil pH values were determined with soil-to-water ratio of 1:2.5. Total organic carbon (Corg) was determined by wet combustion with potassium dichromate and concentrated sulfuracid according to Turin method. Exchangeable cations were extracted with ammonium chloride. Iron was determined in the Tamm (oxalate) extracts. Particle size distribution was analyzed by the pipette method according to Kachinsky. Textural

[1] Guidelines for Soil Description. 4th edition. FAO, Rome, 2006. 97 p.

classes were approximated according to Guidelines for Soil Description. Soil types were determined according to IUSS Working Group WRB, 2015[1]. Soil color was determined in the dry state using Munsell color charts.

In two sampling plots the litter thickness was taken into account. Samples of forest litter were collected for analyzing the reserves and component composition using a template (0.5×0.5 m) in 10 replicates during the summer period according to the methods proposed [Rodin et al., 1968].

Results and discussion

Sampling plot 854 (51° 44' 45.38'' N и 107° 34' 1.21'' E) was studied on the northeast-facing slope of the local ridge of 25°; it is elevated at 854 m a.s.l. Sampling plot 854 is relative to the control. Taxation characteristic of stand not covered by fire >10 years are: the tree storey is formed by the Scots pine (Pinus sylvestris) (10P); the age of the pine trees is 40–60 years; the height is 12–15 m; class bonitet's IV; crown density, 0.6 and the undergrowth of pine is 10-11 years. The plant community is a pine forest with *Rhododendron dauricum* L., *Vaccinium vitis-idaea* subsp., *Bromopsis inermis* (Leysser) Holub, *Artemisia tanacetifolia* L., *Denranthema zawadskii* (Herbich) Tzvel, *Lathyrus humilis* (Ser.) Sprengel. The projective cover is 40–45%. Mosses are presented *Dicranum polysetum* Sw., *Pleurozium schreberi* (Brid.) Mitt. Lichen is presented *Cladonia amaurocraea* (Flk.) Schaer. The projective cover of moss and lichen cover is 60%. This soil is classified as Eutric Brunic Arenosol (Ochric).

The soil has the following horizonation: O (0–14 cm)–AhB (14.5–17 cm)–Bw1 (17–26/30 cm)–Bw2 (26/30–45 cm)–BC (45–70 cm)–C (>70). The litter consist Oi-Oe-Oa layers, very dark brown; loose (7.5YR 3/2). The Oi layer is undecomposed pine needle litter. The Oe layer is strongly decomposed plant residues. The Oa layer is completely decomposed litter. Fungal hyphae are present. A black carbonaceous subhorizon is observed in profile at a depth of 14–14,5 cm with abundance from of charcoals, loose. The AhB horizon is dark brown (10YR 3/2) dry loamy sand with a crumb structure; with inclusions of a large amount of coals and roots; gradual transition. The Bw1 horizon is brownish dark gray (10YR 4/2) dry loamy sand with a crumb structure; slightly compacted; with inclusions of roots; pocket-shaped lower border, gradual transition. The Bw2 horizon is brownish gray (10YR 4/4) dry loamy sand with a crumb structure; slightly compacted; with inclusions of roots; gradual transition. The BC horizon is yellowish-brown (10YR 5/4) dry loamy sand with a crumb structure; slightly compacted; gradual transition. The C horizon is brownish-yellow (10YR 5/8) dry sand; structureless. It does not effervesce with 10% HCl. On the side wall of the soil pit an ocher mottle with a depth of occurrence 17-53 cm is observed.

Sampling plot 854a (51° 44' 45.07'' N и 107° 34' 1.33'' E) was excavated to 5 m from pit 854 on the southwest. A wildfire occurred 2 years early. The consequences of the recent fire are as follows: surface charring of the tree and deadwood bark, fall of dead needles, partial incineration of the forest litter, and complete destruction of the moss–lichen cover. Pine undergrowth partially damaged by fire. Grass and forb communities are represented by secondary successions with *Calamagrostis epigeios* (L.) Roth,

[1] IUSS Working Group WRB. World Reference Base for Soil Resources 2014, update 2015. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. World Soil Resources Reports. FAO. Rome, 2015. No.106. 192 p.

Bromopsis inermis (Leysser) Holub. *Rhododendron dauricum* L. is damaged by fire. The projective cover is 2–3%.

The soil profile consists of the following horizons: O (0–2 cm)–AhB (2–17/26 cm)–Bw1 (17/26–40 cm)–Bw2 (40–68 cm)–BC (68–102 cm)–C (>102). The Oi horizon is presented of semi-burnt litter (mainly from pine bark and needles, small branches) with inhomogeneous color, generally black, dense (7.5YR 2.5/2). Fungal hyphae are present. The AhB horizon is dark brown (10YR 3/2) dry loamy sand with a crumb structure; with inclusions of ferruginous ocher spots and a large number of coals and roots; abrupt transition. The Bw1 horizon is brownish dark gray (10YR 4/2) dry loamy sand with a crumb structure; slightly compacted; with inclusions of ferruginous ocher spots, coals and roots; pocket-shaped lower border, gradual transition. The Bw2 horizon is brownish gray (10YR 4/4) dry loamy sand with a crumb structure; slightly compacted; with inclusions of ferruginous ocher spots and roots; gradual transition. The BC horizon is yellowish-brown (10YR 5/4) dry loamy sand; structureless; with inclusions of ferruginous ocher spots; gradual transition. The C horizon is brownish-yellow (10YR 5/8) dry sand; structureless. It does not effervesce with 10% HCl. On the side wall of the soil pit an ocher mottle with a depth of occurrence 17-44 cm is observed.

Comparative analysis of two sampling plot showed the following patterns.

Forest litter is one of the most important indicators reflecting the wildfire severity [Certini, 2005; Dymov et al., 2021; Shakhmatova et al., 2021]. Surface fires selectively affect its components. It is determined by the combustion temperature generated by a fire. It is known there was a strong litter burnout during high severity fires in the forests of Baikal region. It can be the cause of soil and ecosystem degradation [Krasnoschekov, 2019].

The occurrence of forest fires is influenced by the moisture content in the litter, which is an important indicator for monitoring forest fire danger [Sychev et al., 2020].

The litter in the sampling plot 854 was characterized by high values of thickness and reserves (Table 1). It mainly consisted of weakly- and semi-decomposed needles and tree bark damaged by fire. It is revealed the presence of many small fragmented coals is formed as a result of a surface fire that took place more than 10 years ago. The formed black carbonaceous subhorizon at a depth of 14–14.5 cm indicates repeated fires in this area. Resistant products of fires (charcoals, soot) are retained in soils for several centuries [Maksimova & Abakumov, 2015]. The high value of mosses and lichens in the litter components indicates favorable conditions that developed in the post-fire period.

Table 1

Variations of the thickness, reserves and components of forest litter

Thick-ness, cm	Reserves (absolutely dry weigth), t/ha	Components, %						
		Charcoal	Rotten material	Moss, lichens	Bark	Needles	Branches	Grasses
Sampling plot 854 (area affected by fire >10 years ago)								
13±0.9	20.5±0.9	6	48	6	9	17	12	2
Sampling plot 854 a (area affected by fire 2 years later)								
2.1±3	12.3±1.1	5	58	-	5	12	15	5

A repeated surface fire (Sampling plot 854a) of low-severity led to the complete burning of the litter. Noticeable changes were found in litter component composition. The composition of the litter in the second year after the fire was distinguished by a high content of fresh needles and large charred residues against the background of a decrease in bark, fragmented material, and a complete absence of moss and lichens.

The color of the litter on the test plot 854a changed towards blackening (7.5YR 2.5/2 on the Munsell color charts). The blackened litter indicates that during the fire there was not enough heat generated to completely burn the litter [Xue et al., 2014]. This suggests that the fires were of low-intensity.

Consequently, periodic fires of low-severity occurring in the study area caused a short-term transformation of the litter. They lead to partial mineralization of the litter, reduced its reserves and reduced the thickness. As a result, some litter fractions were partially or completely lost, while others appeared or their content increased.

Thus, low-severity surface fires in the studied pine forests have a positive effect, since they activate the processes of litter decomposition and further dissolution of organic substances that provide soil and plants with accessible elements.

Fires of low-severity lead to changes in the physicochemical properties of soils in semi-arid forest ecosystems of Western Transbaikalia. Eutric Brunic Arenosol is characterized by loamy-sand and sand textural classes. Fractions of fine sand and coarse dust are predominating. An analysis of the granulometric composition of soils in the second year after the fire showed that there was an increase in the values of the clay fraction by 1–2% (Table 2).

Table 2

The granulometry of the soils

Horizon	Depth, cm	Particle size (mm) distribution Russian traditional fraction groups						Textural classes (FAO, 2006)
		1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	
Sampling plot 854 (area affected by fire >10 years ago)								
AhB	14.5-17	1	64	21	3	5	6	Loamy sand
Bw1	17-26/30	1	60	24	3	5	7	Loamy sand
Bw2	26/30-45	1	58	25	2	7	7	Loamy sand
BC	45-70	1	64	21	3	4	7	Loamy sand
C	>70	4	80	11	1	1	3	Sand
ocher mottle	17-53	2	43	39	5	4	7	Loamy sand
Sampling plot 854 a (area affected by fire 2 years later)								
AhB	2-17/26	2	61	23	4	3	7	Loamy sand
Bw1	17/26-40	6	62	18	2	4	8	Loamy sand
Bw2	40-68	2	48	31	7	3	9	Loamy sand
BC	68-102	15	54	25	1	3	2	Loamy sand
C	>102	35	59	3	1	1	1	Sand
ocher mottle	17-44	13	18	58	2	1	8	Loamy sand

In post-fire soil (sampling plot 854a) the humus content sharply decreased by 3 times, as well as the C/N ratio (Table 3). The cation exchange capacity (CEC) of the soil decreased by more than 2 times as a result of the drop in organic matter in the soil. The pH value of the soil solution increased by 1 unit. The formation of ocher mineral mottles indicates the release of iron from minerals during fires. The maximum in its content in the humus horizons is noted, where it is bound by humic acids. A sharp increase in the content of amorphous iron occurs in the horizons and mottles altered by the fire.

Table 3

Selected phisicochemical properties of the soils

Horizon	Depth, cm	pH_{H2O}	C org, %	N, %	C/N ratio	CEC, cmol kg^{-1}	Base sat., %	Tamm Fe_2O_3, %	Munsell color (dry)
Sampling plot 854 (area affected by fire >10 years ago)									
O	0-14.5	6.1	10.4*	-	-	30.5	47	1.12	7.5YR 3/2
AhB	15.5-17	6.1	1.84	0.14	13.1	22.1	73	0.73	10YR 3/2
Bw1	17-26/30	6.5	0.45	0.03	15.0	14.4	90	0.73	10YR 4/2
Bw2	26/30-45	6.5	0.29	-	-	15.2	90	0.58	10YR 4/4
BC	45-70	7.0	0.17	-	-	16.4	93	0.47	10YR 5/4
C	>70	6.8	0.11	-	-	11.0	95	0.40	10YR 5/8
ocher mottle	17-45	6.0	0.36	-	-	12.9	80	0.99	10YR 4/2
Sampling plot 854 a (area affected by fire 2 years later)									
O	0-2	6.4	8.7*	-	-	27.0	42	1.72	7.5YR 2.5/2
AhB	2-17/26	6.4	0.65	0.06	10.8	12.0	72	1.25	10YR 3/2
Bw1	17/26-40	7.0	0.15	-	-	12.0	89	0.91	10YR 4/2
Bw2	40-68	6.9	0.07	-	-	17.2	92	0.73	10YR 4/4
BC	68-102	7.2	0.05	-	-	9.0	93	1.31	10YR 5/4
C	>102	7.0	0.01	-	-	7.5	93	0.54	10YR 5/8
ocher mottle	26-51	6.8	0.20	-	-	17.2	90	1.10	10YR 4/2

* Loss on ignition CEC — cation exchange capacity

Conclusions

Impacts of wildfire low-severity on soil properties on 2 sampling plots of the dry pine forest are studied. Pyrogenic morphological features persist for a long period after a fire. These include the presence of black carbonaceous subhorizon at a depth of 14–14.5 cm, ocher mottles along the roots of burnt trees. These features are shown in the increased content of iron in the Tamm extract and exchangeable bases. This creates conditions for the fixation of humus associated with both calcium and iron hydroxides. Also there is a slight increase in the content of the clay fraction.

There is a post-fire succession in the vegetation cover, *Calamagrostis epigeios* (L.) Roth, *Bromopsis inermis* (Leysser) Holub are the first to appear, in the grass-shrub layer, *Rhododendron dauricum* L. is damaged by fire.

Thus, two years after the fire, the properties of the soil change significantly. Eleven years after the fire, most soil properties are quickly restored to pre-fire levels.

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ВЛИЯНИЕ ПОЖАРОВ СЛАБОЙ ИНТЕНСИВНОСТИ НА СВОЙСТВА ПОЧВ В СЕМИАРИДНЫХ ЛЕСНЫХ ЭКОСИСТЕМАХ ЗАПАДНОГО ЗАБАЙКАЛЬЯ

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Аннотация. Изучено влияние лесных пожаров слабой интенсивности на свойства почв в двух пробных участках сухого соснового леса в Западном Забайкалье. Поверхностные пожары слабой степени тяжести оказывают положительный эффект, поскольку активизируют процессы разложения подстилки и дальнейшего растворения органических веществ, обеспечивая почву и растения доступными элементами. Пирогенные морфологические признаки сохраняются в течение длительного периода после пожара.

К ним относится наличие черного углистого субгоризонта на глубине 14–14,5 см, охристых пятен вдоль корней сгоревших деревьев. Эти особенности проявляются в повышенном содержании железа в вытяжке Тамма и обменных оснований. Это создает условия для фиксации гумуса, связанного как с гидроксидами кальция, так и железа. Также наблюдается незначительное увеличение содержания илистой фракции. Через два года после пожара свойства почв значительно меняются. Через одиннадцать лет после пожара большинство свойств почвы быстро восстанавливаются до уровня, существовавшего до пожара.

Ключевые слова: семиаридные экосистемы, пожар слабой интенсивности, лесная подстилка, почвенные свойства.

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