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RESEARCH IN THE BAIKAL WATERSHED

Postfire Transformations in Pine Forests in the Mid-Mountain Part of the Selenga River Basin (Western Transbaikalia)

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Abstract—This paper examines fire-induced transformations of the main ecosystem components in steppificated pine forests that grow in the mid-mountain part of the Selenga River basin (Western Transbaikalia). It has been established that medium-intensity ground fires that occur most frequently in the region transform the living ground cover and alter the composition and properties of forest litter, as well as the morphological, physicochemical, and hydrothermic properties of soils. The changes in the species diversity, projective cover, and phytomass of the herbaceous vegetation observed in the course of the postfire dynamics are minor. In contrast, the parameters of the moss–lichen cover, forest litter, and soils undergo significant transformations. In recently burned areas, mosses and lichens are completely destroyed; while the forest litter is thin, consists primarily of recently fallen needles and branches, and its reserves are low. Immediately after a fire, the moisture content in the upper pyrogenic soil horizons decreases, while the soil temperature increases. The following pyrogenic signs are observed in the humus-accumulative horizons of the soil profile: very dark coloration of organic matter combustion products, alkalization, and increased concentrations of calcium and carbon cations; concurrently, an increase in content of oxalate-soluble iron is observed in the illuvial horizons. At 5 or more years after a ground fire, a number of positive changes are observed, including an increase in forest litter thickness, formation of the moss–lichen cover, gradual changes in the chemical properties, a decrease in soil temperature, and some stabilization of field moisture parameters in the upper part of the soil profile. It has been established that the pyrogenic transformations of the forest litter, moss–lichen cover, and soils adversely affect the postfire restoration of the forest vegetation and regeneration of pine stands in areas affected by medium-intensity ground fires.

Keywords: dry pine forests, ground fires, soils, vegetation, postpyrogenic changes, reforestation

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INTRODUCTION

Forest fires are an active factor that affects the transformation and dynamics of natural complexes [1, 2]. In semiarid regions they often induce the development of soil erosion, as well as degradation and desertification processes [3, 4].

The mid-mountain part of the Selenga River basin is a part of the Lake Baikal basin. In the north, it borders on the Chamar-Daban and Ulan-Burgasy Ridges; in the east and southeast, on the Vitim Plateau and Khentei-Chikoi Upland; in the south, Mongolia; and in the southwest and west, the northern slope of the Dzhida Ridge and southwestern slope of the Small Chamar-Daban Ridge [5]. The economically developed area is densely populated and actively used in forestry and agriculture. Its vast mountain–forest–steppe landscapes are occupied by pine forests that grow on sandy–sandy-loam environmentally sensitive soils. Severe anthropogenic impacts on these forests (fires, felling, pasturing, etc.) affect the surface runoff, thus, intensifying erosion processes. In recent years, fires have been the primary forest disturbance factor in the region. Active pyrogenesis-related effects caused by anthropogenic impacts and climate aridity result in the destruction of light-coniferous forests and intensify the general trend towards local deforestation [6–8].

The role of the pyrogenic factor in pine forests of Siberia is well researched, including its positive and adverse impacts and their relationships with the regional climate, relief, and fire intensity, and type. However, a comparative pooled analysis of pyrogenic changes has been performed primarily for middle- and south-taiga pine forests [9–13]. No such complex studies taking the transformations of the key landscape components into account were conducted in vulnerable mountain–forest–steppe pine forests in the mid-mountain part of the Selenga River basin, which is frequently affected by ground fires. The available data are limited to the following topics: regional soils, their environmental zoning and transformation, and restoration of normality in pine stands affected by fires [6, 14–17]. However, fires affect all landscape elements and determine the integral sustainability of forests in the region. Accordingly, the purpose of this study was to examine postpyrogenic changes in the vegetation, moss–lichen cover, forest litter, and soils and assess their impacts on the postfire recovery of pine forests in the mid-mountain part of the Selenga River basin.

MATERIALS AND METHODS

The studies were carried out in 2008, 2009, 2010, and 2013 in pine forests growing on northern offshoots of the Tsagan-Daban Ridge in the Vorovka River basin. The climate in the study area is extremely continental. The average annual air temperature varies from –4.2 to –5°C. The average annual precipitation is 250 mm. In spring and early summer, the air and soil are very dry, precipitation is insignificant, while winds are strong. The relative air humidity in this period does not exceed 30–40%; on some days it is 10% [18].

Three pine forest sites that are relatively homogeneous in their environmental parameters (topographic position, absolute altitude, soil type, and parent rocks) that were affected by fires recently, 5 years ago, and 10 years ago were selected for the analysis of postfire changes. Sampling plots were established on each of these sites confined to lower parts of deluvial plumes on shady-exposure slopes and located at altitudes of 600–750 m above sea level. Sampling plot 1 (51°37′51″ N, 107°51′18″ E) is a dead-cover pine forest affected by fire in early summer of 2008 (i.e., it recently burned at the beginning of the study). Sampling plot 2 (51°44′07″ N, 107°48′26″ E) is located in a gramineous–forb pine forest affected by fire in 2003 (i.e., at the beginning of the study the postfire period was 5 years). Sampling plot 3 (51°41′15″ N, 107°48′07″ E) was established in a rhododendron–forb–lichen pine forest, affected by fire in 1998 (i.e., at the beginning of the study the postfire period was 10 years). No forest areas that was never affected by the pyrogenic factor in the past could be identified within the study area; therefore, it was impossible to establish a sampling plot to be used as the control variant. The burned areas were affected by medium-intensity ground fires. The *Forest Fire Book*[1] was used to determine the age of the fires.

The sampling plots were used to collect the following data: information on the plant communities; pine regeneration rate; aboveground phytomass and projective cover of the grass stand, mosses, and lichens; forest litter thickness and reserves (n = 10); and the fractional composition of the forest litter (n = 4). In addition, soil profile cuts were established (n = 4) to study the soil morphology and properties. The soil moisture content and temperature were measured over the course of the growing seasons in 2008, 2009, and 2013 [19–22]. The Latin plant names are provided in accordance with [23]. The statistical data processing was performed in Microsoft Excel.

RESULTS AND DISCUSSION

Dry pine forests represent a significant vegetation cover background in mountain–forest–steppe landscapes in the mid-mountain part of the Selenga River basin. Distinct features of the climate, topography, and vegetation cover are the reasons for the high frequency of fires in pine forests.

On the recently burned site, the tree storey is formed by the Scots pine (*Pinus sylvestris*) (10P). The age of the pine trees is 60–100 years; the height is 10–14 m; quality class V; and crown density, 0.5. The undergrowth and young growth are completely destroyed. The 5–80-cm high grass–dwarf-shrub storey is sparse and mosaic. The predominant species are *Lathyrus humilis*, *Aster alpinus*, *Antennaria dioica*, *Dendranthema zawadskii*, and *Bromopsis sibirica*. Their projective cover is 2–3%. In total, 21 plant species were noted. 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. The regeneration of *Rhododendron dauricum* from buds is noted.

On the site affected by fire 5 years ago, the tree storey is formed by the Scots pine (10P). The age of the pine trees is 70–110 years; height, 8–15 m; quality class V; and crown density, 0.4. Some of the trees dried and perished; an insignificant portion of the trees were cut down; as a result, the stand is sparse (the projective cover is 40%). The 0.5–0.8-m high undergrowth is constituted by *Rhododendron dauricum*, *Spiraea media*, and *Rubus sachalinensis*; its projective cover is 1–2%. The grass–dwarf-shrub storey is 5–40 cm high, sparse, and homogenous. In total, 23 plant species were noted. The dominants are *Antennaria dioica*, *Dendranthema zawadskii*, and *Calamagrostis epigeios*. The consequences of the fire are as follows: lack of young growth (dead pine sprouts were noted) and a poorly developed moss–lichen cover constituted by two green-moss species.

On the site affected by fire 10 years ago, individual old stumps remaining from an old felling and large amounts of deadwood at the second and third decomposition stages (dust) are present. The tree storey is formed by the Scots pine (10P). The age of pine trees is 60–100 years; height, 10–14 m; quality class V; and crown density, 0.6. No young pine growth was noted (sprouts occur in the grass–dwarf-shrub storey). *Rho-*

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[1] *Forest Fire Books* are record books maintained by foresters of Zaudinskii Forest Enterprise, Republic of Buryatia in the period of 1990–2008.

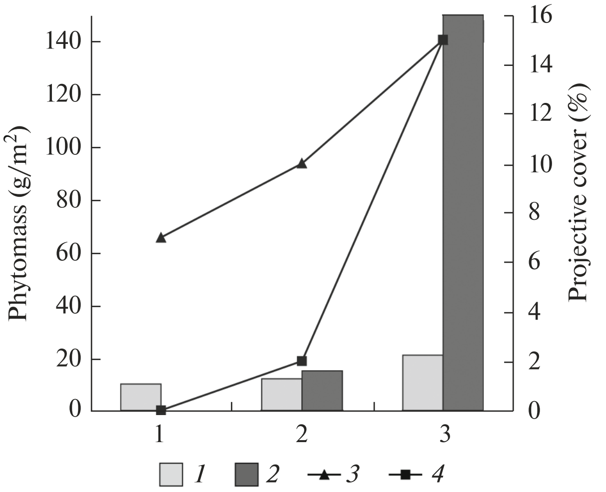

Fig. 1. The phytomass and projective cover of the grass and moss–lichen storeys on sampling plots. Phytomass: (*1*) grass stand, (*2*) mosses and lichens. Projective cover: (*3*) grass storey, (*4*) moss–lichen storey.

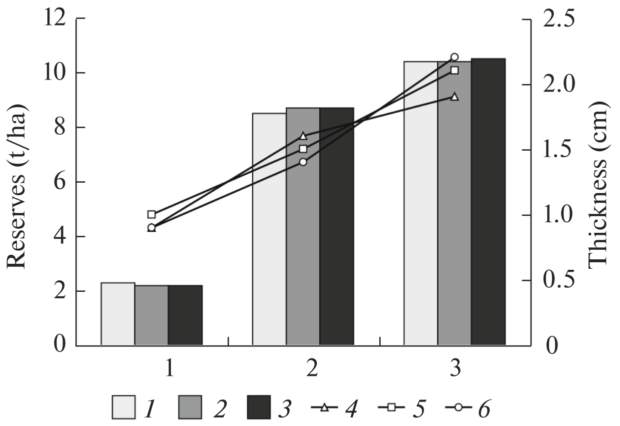

Fig. 2. The dynamics of the forest litter reserves and thickness on sampling plots. Forest litter reserves: (*1*) 2008, (*2*) 2009, (*3*) 2010. Forest litter thickness: (*4*) 2008, (*5*) 2009, (*6*) 2010.

dodendron dauricum was noted in the undergrowth. Its height is 1 m on average; its projective cover is 10%. The grass–dwarf-shrub storey is sparse and homogenous, up to 15-cm high. In total, 29 plant species were noted; *Antennaria dioica* predominates among them. The mosaic moss–lichen cover is present in clumps (four moss species and four lichen species were identified).

As the postfire period increases, the number of species in plant communities grows. In the dead-cover pine forest, the projective cover of the grass storey decreases insignificantly (by 3%). On the one hand, this enables the postfire regeneration of the pine stand (the basis of the pyrogenic pine forest dynamics in the region). On the other hand, a decrease in the projective cover of the grass storey is caused by the decrease in forest litter thickness and respective deterioration of the hydrothermic conditions. A significant increase in this parameter is observed in the rhododendron–lichen pine forest. At 5 years after the fire, the grass stand phytomass increases insignificantly; by contrast, 10 years after the fire, it increases by more than two times (Fig. 1).

On the recently burned site, mosses and lichens were completely destroyed by high-temperature impacts during the fire. On the site affected by fire 5 years ago, their appearance is noted, which plays a positive role at the recovery stage of the postpyrogenic ground cover succession. At ten years after the fire, the phytomass of mosses and lichens is much larger, and their projective cover increases by 7.5 times.

The fires transformed the forest litter and weakened its protective and regulatory functions. On sampling plot 1, the forest litter thickness and reserves are insignificant. Immediately after the fire and in the 2 subsequent years, the litter thickness remained up to 1 cm; its reserves were up to 2.5 t/ha. On sampling plots 2 and 3, an expected increase in the studied parameters was noted (Fig. 2).

The fractional composition of the litter in the first year after the fire showed a high content of fresh needles and coals, while the shares of other litter fractions were low (Fig. 3). As the postfire period increases, the forest litter composition changes: the needle fraction content decreases by almost 3 times; while the share of coals, by 4–6 times. At 5 years after the fire, the content of such fractions as cones, branches, and bark increases noticeably due to their death and falling from damaged trees. The dust fraction content increases with the inflow, accumulation, and slow decomposition of litterfall under the sharply continental climatic conditions. In other words, the fire effect is reflected in changes observed in individual forest litter components, as well as in the litter thickness and reserves; while the length of the postfire period affects the litter recovery rate.

A differentiation in the morphological structure is observed in the upper horizons of soils under the studied postfire pine forests; the degree of differentiation depends on the length of the postfire period. As a result of the fire-induced transformations of the forest litter and humus horizon, the following pyrogenic signs are manifested in soils of the recently burned site: compaction, low thickness, and very dark coloration of these horizons due to inclusions of coaly dust and numerous black charcoals. A wavy or pocket-like border of the transition to the illuvial horizon is observed below. The BF horizon is compacted in the upper part; its color is brownish-ochreous with spots, inclusions, and streaks of dark gray and brown matter. The morphological structure of the sod–podzolized brown soil profile is Opir-AYpir-BF1-BF2-C.

In sod–podzolized brown soils that have not been affected by fire for a long period of time, litter passes down the soil profile into a dark gray humus-accumulative horizon (AY) up to 10-cm thick. A transitional horizon that includes a part of AY and the brownish or brownish-ochreous illuvial horizon (BF) is located under it. Below, in the mineral part of the soil profile, the presence of ferruginous-manganese smears is noted. The morphological structure of the soil profile is O-AY-AYBF-BF1-BF2-C1-C2.

Pyrogenic impacts on the upper soil horizons are noticeably reflected in such parameters as soil reaction and the contents of carbon, nitrogen, and exchangeable cations. On sampling plot 3, the litter has acidic pH values; while on sampling plot 1, the reaction of forest litter is close to neutral (Table 1). The postfire decrease in acidity is also observed in humus horizons of the studied soils. On the recently burned site, the content of calcium cations in the forest litter, the C : N ratio in the humus horizon, and the content of oxalate-soluble iron in the illuvial part of the soil profile increase. Immediately after the fire, the carbon content in the soil is relatively higher in comparison with soils on sites affected by fire 5 and 7 years ago. A decline in nitrogen content occurs due to the partial combustion of its organic compounds. As the postfire period increases, pH values and the content of exchangeable cations, amorphous iron, and carbon decrease in forest litter and soils; while the nitrogen content and carbon enrichment with nitrogen in the humus horizons increase.

Forest fires significantly alter the water and temperature regimes in soils. Pyrogenic impacts on soils of pine forests growing in a humid climate cause an increase in liquid phase content in them [24]; while soils of dry pine forests sustain pyrogenic losses of the liquid phase due to more intense heating of the burned soil surface in the daytime [25].

The soils of the sampling plots have low moisture content values in the root layer, which is determined by their physical properties (light granulometric composition and poor moisture retention capacity).

In mid-July of 2008, field moisture in the upper soil horizons under the dead-cover pine forest was higher in comparison with the values observed in subsequent years (Table 2). This phenomenon was caused by a decrease in water consumption by vegetation that constitutes the lower storeys immediately after the fire and by the pyrogenic transformation of the ground cover and litter that normally act as moisture accumulators. The latter factor is confirmed both by the absence of mosses and lichens and by low reserves of charred litter on the recently burned site. In that year, soil moisture values were higher in all soil layers under the gramineous–forb and rhododendron–lichen pine forests.

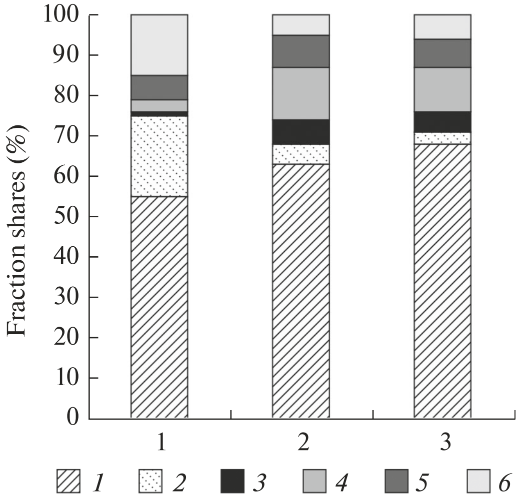

Fig. 3. The forest litter fractional composition on sampling plots. (*1*) dust, (*2*) coals, (*3*) cones, (*4*) branches, (*5*) bark, (*6*) needles.

On the site affected by fire in 2008, the moisture content in the upper soil horizons decreased in the second and fifth years of the study and their noticeable drying was noted. In 2009, this was caused by a smaller amount of precipitation during the observation period and high moisture consumption for physical evaporation after the last year's fire. In addition, soils recently affected by fire can be dry both due to their elevated hydrophobicity, which increases under the impact of high temperatures [26] and due to an increase in the postfire surface runoff on the slopes [6]. Clearly manifested differences in moisture content can be observed in soils of burned areas down to a depth of 10 cm. On sampling plot 1, forest litter thickness reached the level sufficient to stabilize the moisture content in the upper part of the soil profile 5 years after the fire.

The soil temperature under the dead-cover pine forest had also changed significantly. In July 2008, it was higher in comparison with the soil temperature under the gramineous-forb pine forest and significantly higher than that under the rhododendron–lichen pine forest (Table 3). This is because a dark soil surface lacking herbaceous vegetation in some places is heated faster. In 2009, the soil temperature increased on all sampling plots. The differences in temperature values were clearly manifested on the surface and in the upper layers of the soil profile. The maximum difference between the soil surface temperatures on different sampling plots exceeded 6°C in 2009. A decrease in soil temperature on the site burned in 2008 was registered 5 years after the ground fire.

In Siberian mid-taiga pine forests, fires have a positive impact on the initial forest formation stage [1]. In contrast, adverse impacts of fires on the reforestation processes have been identified in steppificated pine forests in the mid-mountain part of the Selenga River basin. These adverse impacts are primarily determined by pyrogenic transformations of forest litter and hydrothermic soil properties. The temperature of the

Table 1. The chemical parameters of soils on the sampling plots, %

Horizon	Depth (cm)	$pH_{aqueous}$	Exchangeable cations (cmol-equiv/kg)		Fe^{3+} (Tamm's extract)	C	N	C : N
			Ca^{2+}	Mg^{2+}	%			
Sampling plot 1 (recently burned area)								
Opir	0–1	6.1 ± 0.05	19.1 ± 0.4	1.1 ± 0.2	–	–	–	–
AYpir	1–5	6.5 ± 0.04	10.8 ± 0.4	9.5 ± 0.4	0.64 ± 0.04	1.5 ± 0.03	0.07 ± 0.004	21
BF1	11–21	6.3 ± 0.04	6.7 ± 0.3	3.3 ± 0.3	0.72 ± 0.04	0.3 ± 0.05	0.02 ± 0.003	15
BF2	27–38	6.5 ± 0.03	7.5 ± 0.3	2.5 ± 0.2	0.64 ± 0.03	0.2 ± 0.03	0.01 ± 0.002	20
C	70–80	6.7 ± 0.03	8.3 ± 0.3	4.2 ± 0.2	0.50 ± 0.03	0.1 ± 0.02	–	–
Sampling plot 2 (area affected by fire 5 years ago)								
Opir	0–1	5.7 ± 0.05	16.1 ± 0.4	3.6 ± 0.3	–	–	–	–
AYpirBF1	1–8	6.3 ± 0.04	8.3 ± 0.4	6.7 ± 0.3	0.60 ± 0.03	1.0 ± 0.04	0.06 ± 0.003	17
BF1	19–29	6.3 ± 0.03	4.4 ± 0.3	4.3 ± 0.3	0.64 ± 0.04	0.2 ± 0.02	0.01 ± 0.003	20
BF2C	42–52	6.6 ± 0.04	4.2 ± 0.3	4.2 ± 0.3	0.52 ± 0.03	0.1 ± 0.03	–	–
C	71–81	6.9 ± 0.03	3.1 ± 0.2	3.1 ± 0.2	0.32 ± 0.03	0.1 ± 0.02	–	–
Sampling plot 3 (area affected by fire 10 years ago)								
O	0–1/1.5	5.3 ± 0.04	13.5 ± 0.4	5.8 ± 0.3	–	–	–	–
AYBF1	1/1.5–4	6.1 ± 0.04	14.3 ± 0.4	3.6 ± 0.3	0.48 ± 0.03	1.4 ± 0.03	0.09 ± 0.004	16
BF1	9–19	6.3 ± 0.03	10.0 ± 0.4	3.9 ± 0.2	0.56 ± 0.04	0.3 ± 0.04	0.02 ± 0.003	15
BF2	24–35	6.4 ± 0.03	8.0 ± 0.3	6.0 ± 0.3	0.44 ± 0.03	0.1 ± 0.02	–	–
C1	35–47	6.6 ± 0.02	5.0 ± 0.3	5.0 ± 0.3	0.40 ± 0.03	0.1 ± 0.02	–	–
C2	51–61	6.9 ± 0.03	4.6 ± 0.3	2.3 ± 0.2	0.40 ± 0.03	0.1 ± 0.02	–	–

Note: (–) parameter was not measured.

Table 2. The average field moisture values in soils on the sampling plots (%)

Sampling plot no., postfire period	Precipitation in July, mm	Depth, cm				
		0–5	5–10	10–15	15–20	20–25
Second decade of July 2008						
1, recently burned	60.5	13.05	10.03	9.99	9.57	9.03
2, 5 years		15.57	9.93	10.37	9.58	8.91
3, 10 years		20.94	12.41	12.14	11.85	10.30
Second decade of July 2009						
1, recently burned	56.5	10.05	9.73	9.03	8.62	8.59
2, 5 years		10.83	9.85	9.10	8.75	8.67
3, 10 years		11.13	10.25	9.05	8.97	8.69
Second decade of July 2013						
1, recently burned	22.1	9.96	8.89	8.47	8.19	8.07
2, 5 years		11.93	11.15	8.92	8.13	8.01
3, 10 years		11.17	9.32	8.95	8.51	8.29

Table 3. The average soil temperature values on sampling plots, °C

Sampling plot no., postfire period	Air temperature (max) in July, °C	Depth, cm				
		0	5	10	15	20
Second decade of July 2008						
1, recently burned	30.5	22.9	19.5	19.2	18.5	17.5
2, 5 years		19.5	18.9	18.0	16.9	16.0
3, 10 years		15.4	14.9	13.9	13.5	13.2
Second decade of July 2009						
1, recently burned	32.5	24.2	20.2	19.7	18.9	17.9
2, 5 years		21.1	19.7	18.5	16.9	16.7
3, 10 years		17.9	15.7	14.5	14.2	14.2
Second decade of July 2013						
1, recently burned	29.5	20.1	19.3	18.3	17.1	16.1
2, 5 years		16.3	15.5	14.9	14.2	14.0
3, 10 years		16.5	15.8	14.3	14.0	13.9

dark degraded soil surface is rather high, which is detrimental to the natural pine regeneration processes in areas affected by fire; in addition, the moisture content in the humus horizons is insufficient for successful sprouting of Scots pine [27].

In 2009, the number of seedlings at an age of 1–2 years in the rhododendron–lichen pine forest (affected by fire in 1998) was 3125 individuals per ha of forest area. No pine regeneration was noted in the dead-cover and gramineous–forb pine forests in the studied years.

CONCLUSIONS

Pine forests that grow in the mid-mountain part of the Selenga River basin (Western Transbaikalia) are intensely affected by the pyrogenic factor, which transforms the living ground cover, forest litter, and soils, thus, contributes to the steppification of the area.

In the studied region, the consequences of medium-intensity ground fires include damage to trees, their drying, forest stand sparsity, destruction of young growth and its absence in areas affected by fires years ago, decline in the species diversity in the grass–dwarf-shrub storey, changes in the grass stand phytomass and projective cover, incineration of mosses and lichens, and their slow recovery in the postpyrogenic period.

Immediately after a fire, noticeable changes in the litter thickness, reserves, and fractional composition are observed. As a result, forest litter partially loses its moisture regulation function. The high-temperature impacts result in the formation of thin dark-colored pyrogenic horizons in the upper part of the soil profile. The actual acidity in this zone decreases, the content of calcium and carbon cations increases, the moisture content drops, while the soil temperature increases. At 5 or more years after a ground fire, the following positive changes are observed: formation of the moss–lichen cover, increased thickness of the forest litter, changes in the chemical properties of the soil, lower soil temperatures, and stabilization of field moisture parameters.

The identified transformations of the studied ecosystem components caused by medium-intensity fires worsen the seed germination conditions, thus exercising a limiting effect on the restoration of forest vegetation and regeneration of pine stands in burned areas.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest

The authors declare that they have no conflict of interest.

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