ASSESSMENT OF FIRE RESISTANCE OF FOREST-FORMING SPECIES IN THE KOSTANAY REGION (KAZAKHSTAN)

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ABSTRACT

One of the possible ways to mitigate the negative consequences of forest fires is to increase the fire resistance of forest-forming species. To develop scientifically based fire prevention measures in forests, a comprehensive assessment of the degree of their fire resistance is necessary. The article identifies the main factors that determine the resistance of forest-forming species to fire impact. Factors such as stand diameter, crown distance, root depth, fuel reserves, number and height of undergrowth, as well as the presence of other species were used to assess fire resistance. The degree of fire resistance was evaluated using a point-based system by calculating the sum of weighted points. Field studies were conducted in 2023-2024. The results of the fire resistance assessment of forest-forming species enable the planning and implementation of forestry and fire prevention measures aimed at increasing the resilience of forested areas to fire impact.

Key-words: *Forest; Fire resistance factors; Sample plot; Integral assessment; Kostanay Region.*

1. INTRODUCTION

Today, climate warming in the Northern Hemisphere is accompanied by consequences related to an increase in the number of extreme climate events (Antokhina, Antokhin, Martynova 2016; Cansler & Mckenzie 2014). Under current climatic conditions, the impacts of anthropogenic pressure on the natural environment are exacerbated, and the recovery dynamics of ecosystems require significant time. The frequency of forest fires is rising due to ongoing increases in human exploitation of natural environments, population growth, and the growing importance of forests for recreation (Valendik 2007; Dichenkov 1992). The trend of increasing forest fire occurrences is also expected given climate warming projections (Budyko 1974). One of the key tasks facing forest pyrology is the study and assessment of the primary fire resistance of vegetation cover. This is essential for determining potential fire damage and planning forestry activities aimed at enhancing vegetation's resistance to ignition. One possible approach involves influencing the structure of forest stands.

The topic of fire resistance has been studied by various researchers, including Furaev V.V. (2005), Furaev I.V. (2021), Tsvetkov P.A. (2007, 2019), Archibald et al. (2018), Stevens et al. (2020), Jose V. Moris, Matthew J. Reilly, and others (2022). We define the fire resistance of forest stands as the potential susceptibility of various components of the forest biogeocenosis — primarily the stand, undergrowth, understory, ground cover, and forest litter — to fire damage. Thus, fire resistance reflects the vegetation complex's ability to maintain its viability after a fire. Unlike fire hazard, which assesses the likelihood of a fire occurring, fire resistance characterizes the resilience of a plant community to an ongoing fire.

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Fire resistance is a property of the entire planted vegetation, representing a cenotic form of species resilience to fire impact. In contrast, a pyrogenic property like fire tolerance, which describes the ability of individual trees to withstand heat exposure, is an individual form of species resilience. By the term “fire resistance,” we mean the degree of vulnerability of various components of the biogeocenosis to fire and its importance in forestry. To prioritize these components in terms of their significance for forestry, they can be listed as follows: the stand, undergrowth, living and dead soil, and the biologically active layer of the soil. To obtain a comprehensive understanding of the primary fire resistance of a particular forest stand, a complex assessment of the damage susceptibility of all these components is required (Cansler &Mckenzie 2014; Parks, Dillon, Miller 2014). Researchers emphasize the higher fire resistance of light coniferous species, while deciduous and, especially, dark coniferous species are less resistant to fire. It is noted that light-loving species developed increased fire resistance over the course of evolution (Sofronov 2007). However, there are conflicting opinions in the scientific literature. Some researchers (Sedykh 1991; Sofronov 2007) consider pine to be more fire-resistant, while others (Valendik 2006) argue the opposite.

These contradictions highlight the need for further research on the fire resistance of the main forest-forming species in the study region. With the increasing frequency and combustibility of forest fires, it is necessary to evaluate the suitability of different species. Factors influencing species’ fire resistance include genetically determined responses to environmental conditions, anatomical-morphological and physiological characteristics, as well as regional specificity (Wood 2011).

2. MATERIALS AND METHODS

In this study, the object of research is the forested area of the Kostanay Region. According to the forest fund records for 2024, the area of forested lands in the Kostanay Region is 19,600.1 thousand hectares. The distribution of forest lands in the Kostanay Region by their types within the predominant species is shown in **Figures 1** and **2**.

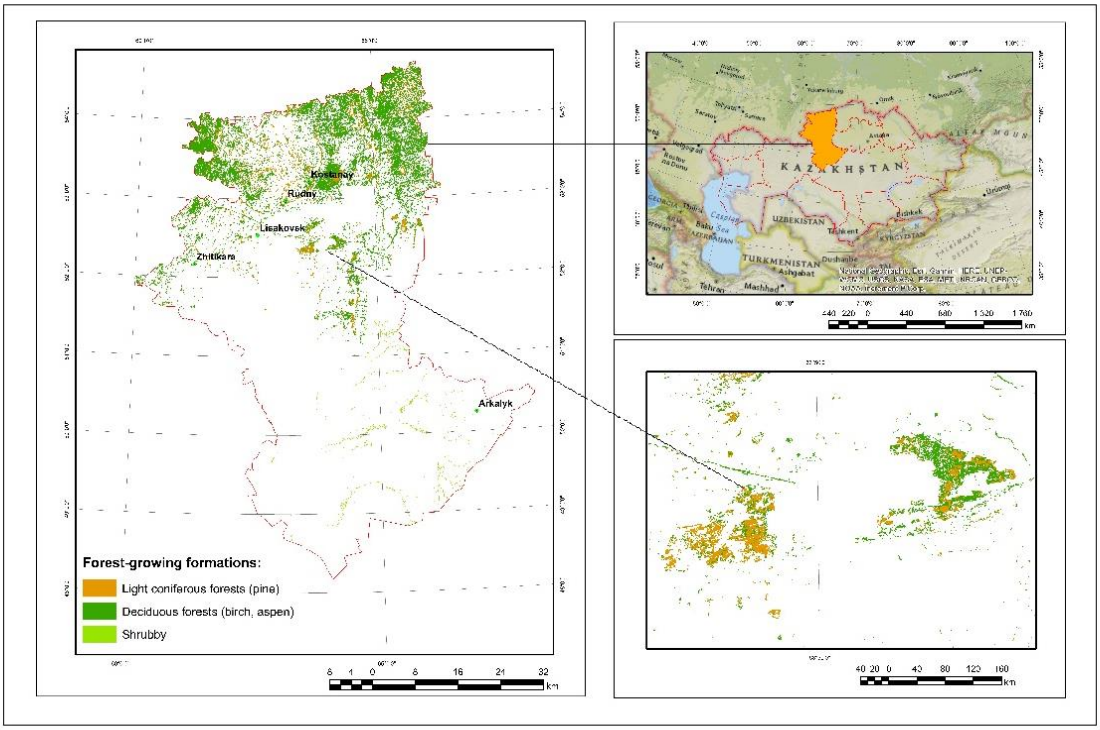

Fig. 1. Map of Forest-Forming Species in the Kostanay Region.

The main forest-forming species is the common pine, with other species including birch, aspen, black saxaul, shrub willow, rosehip, and meadowsweet, forming both pure and mixed stands.

In the process of analyzing the results of cartography and calculating indices, it was found that the most indicative indices for determining tree species of forest vegetation at the level of individual indicators based on Landsat 9 A-B data are the normalized difference vegetation index (NDVI) and the enhanced vegetation index (EVI). The map of forest-forming species in the Kostanay Region is presented in **Figure 1**.

According to the map of fire hazard areas of Kazakhstan, the Kostanay Region falls into the category of high-risk areas with favorable climatic conditions for fire occurrence (Atlas of Natural and Technogenic Hazards and Risks of Emergency Situations in the Republic of Kazakhstan 2005). The combination of insufficient moisture and the shifting towards a more arid continental climate creates a natural environment for the occurrence of forest fires.

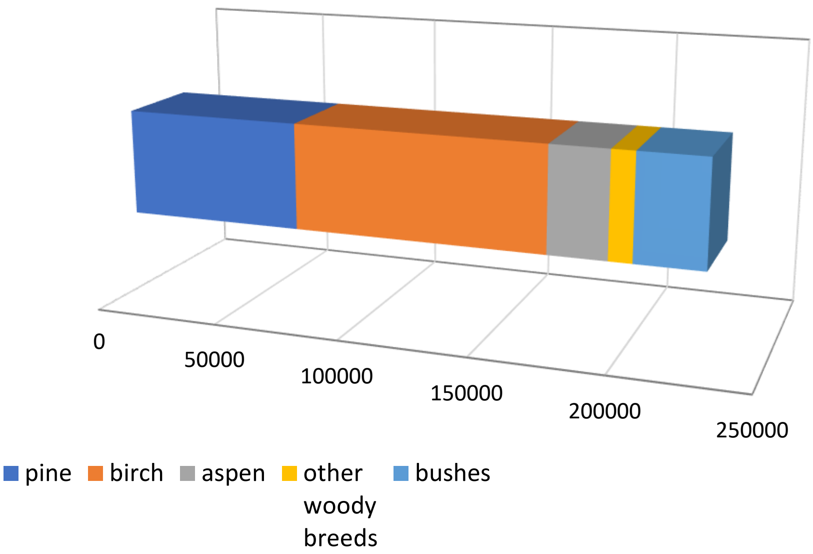

Fig. 2. Distribution of Forest Lands in the Kostanay Region by Type within the Predominant Species, in hectares (Dancheva 2024).

The forests of the Kostanay Region represent a unique natural complex, including island pine forests and birch-aspen mixed stands. They perform important soil- and wind-protecting, climate-regulating, water-protecting, sanitary-hygienic, recreational, and other protective and social functions. The forests are located only on ancient alluvial sands, on the crests of ancient dune ridges, and the upper parts of their slopes.

Birch and aspen forests are typically found in the lower parts of the slopes of sandy ridges and often adjacent to the shores of saline lakes. Shrub willows and honeysuckle are located along the banks of rivers and lakes. Rosehips and meadowsweet grow on the foothills and slopes. On clearings and glades, sandy-steppe and feathergrass steppes form. At the edges of forested areas, narrow strips of meadow-saline vegetation are common.

The frequency and scale of forest fires are increasing in the region. Between 2019 and 2023, significant fire-affected areas were registered, totaling 2,050,428.5 hectares (Official Website of JSC "National Company 'Kazakhstan Space Agency"). The largest fire occurred on September 2, 2022, with the area of the fire covering more than 43,000 hectares out of 106,000 hectares of the forestry's forest fund. Over 90 residential homes were damaged, and such a large-scale fire had not been recorded in the past 30 years. The fire hazard season in the study region is quite prolonged and includes two peaks of fires: the spring-summer and summer-autumn periods. To assess the fire resistance of forest-forming species, factors such as the diameter of the stand, distance to the crown, depth of root systems, reserves of combustible materials, the quantity and height of undergrowth, and the presence of deciduous (other) species were used. All these factors determine the potential susceptibility of the stands to damage and their fire resistance.

Forest-forming species were selected for the study in the territory of the Novonezhinskoye, Kalininskoye forest districts within the Semiozernoye forest management area, as well as the Western Forest district within the Basamanskoye forest management area. Taking into account the types of forest-forming species, on the preparatory stage, we have identified sample plots (SP) using satellite imagery and cartographic materials, which characterize disturbed (post-fire) and background undisturbed forest covers. In addition, the identification of sample plots depends on the nature, shape, intensity, and frequency of the fire. The selection and establishment of sample plots (**Table 1**) were carried out according to the forest management guidelines (2012). Control plots consisted of pine forests adjacent to SP 13, which were affected by fires in 2022. The location of the forest sample plots is shown in **Figure** 3.

The reserves of combustible materials (RCM) in their absolutely dry state were determined using the methodology of N.P. Kurbatsky (1970) (Kurbatsky 1970). The area of the accounting plots for forest stands was 0.25 hectares, with a total of 10 plots. The wet mass of the RCM samples was dried in a thermostatic chamber at 105°C, thus determining their absolutely dry mass. To assess the reserves of logging residues, three accounting plots of 2 × 2 meters each were established on each logging strip. Small logging residues (branches and twigs up to 3 cm in diameter) were collected and weighed using a 20-kg balance scale. Then, samples were taken, dried in a thermostatic chamber to an absolutely dry state, and weighed on electronic scales. Larger logging residues (greater than 3 cm in diameter) were measured by length and median diameter within the accounting plot, and their volume was then calculated. Subsequently, according to the "Short Guide…" (2010), the obtained volume was converted into mass using the formula $M = Q \times K$, where M is the mass, Q is the volume, and K is the density coefficient of the wood (for pine, a density of 500 kg/m³ at 10% moisture content was used).

The depth of the root system was determined using the methodology of S.G. Prokushkin (Abaimov et al.1997). The depth of the skeletal (greater than 5 cm in diameter) and conductive (3-5 cm in diameter) roots extending from the trunk was measured by excavation and measuring their thickness and depth of occurrence in the mineral soil layer (below the forest litter). To do this, the litter was removed, and the roots were excavated on three sides of the tree at distances of 0.2, 0.5, and 1.0 meters from the trunk. Then, the total number of roots was determined, and the thickness of the mineral soil layer from its surface to each root was measured.

In assessing the fire resistance of the stands in the study region, we used the fire resistance assessment principles proposed by P.A. Tsvetkov et al. (2019), I.V. Furyaev (2021), Jose V. Moris, Matthew J. Reilly et al. (2022). The weight values of the selected factors were established using the expert method. According to the methodology for determining weight coefficients, the sum of the weights assigned to a set of events should equal one. Following these rules, the values of the weight coefficients for the factors were determined through a questionnaire survey of experts, and these values are presented in **Table 2**.

For determining the degree of fire resistance, we developed a reference scale for assessing factors, as presented in **Table 2**. Thus, the factor assessing the overall stock of forest fuel materials, the average tree diameter, and the average height of the understory have the greatest influence on the fire resistance of the studied pine forests. It is important to note that the composition and stock of fuel materials affect the fire intensity and combustion rate, while the average tree diameter protects trees from heat exposure, which characterizes their fire resistance. The growth of the understory also plays a role, as its significant density can lead to the transition of a surface fire into a crown fire, which is more dangerous and destructive to the forest. The absence of lower branches reduces the risk of crown fires and, therefore, decreases the exposure of foliage and buds to fire damage (Schwilk & Ackerly 2001; Keeley 2012; Pausas 2015).

Table 1.

Characteristics of the Sample Plots.

Coordinates	№	Names of the forest management areas	Name of the forestry district	Type of forest	Forest compartment number	Forest plot number	Area of the plot, ha	Composition	Average age, years	Average height, m	Average density	Site quality class
52°30´ 21.46´´N 64°4´16. 48´´E	1	Semi-Ozero Forestry Institution	Novonezhinsk (natural)	Fresh pine forests	20	1	9,2	8C 2B	90 50	21 14	0,5	III
52°30´47 .54´´N 64°5´26. 08´´E	2		Novonezhinsk (natural)		9	11	0,2	7C	15	3,3	0,6	III
52°30´24 .12´´N 64°4´0.6 1´´E	3		Novonezhinsk (natural)		7	22	9,2	8C 2B	60 40	14 12	0,5	III
52°29´54 .12´´N 64°12´47 .45´´E	4		Kalininsk (natural)		5	19	16,0	10C +C	50 90	16 17	0,7	II
52°29´47 .79´´N 64°13´52 .47´´E	5		Kalininsk (plantations)		12	6	1,5	10C +C	80 120	16 19	0,6	IV
52°21´30 .18´´N 63°28´41 .52´´E	6	Basamansk Forestry Institution	Western (natural)	Fresh pine forests	69	15	4,9	10C	70	18	0,7	III
52°20´53 .44´´N 63°28´20 .49´´E	7		Western (plantations)		83	11	1,6	10C	55	15	0,5	III
52°20´45 .28´´N 63°28´23 .14´´E	8		Western (natural)		95	9	3,0	10C	60	15	0,5	III
52°20´32 .27´´N 63°28´33 .71´´E	9		Western (natural)		96	27	0,4	10C	70	17	0,5	III
52°20´31 .22´´N 63°28´32 .71´´E	10		Western (plantations)		96	28	0,2	10C	46	13	0,7	III
52°27´17 .02´´N 64°19´10 .66´´E	11	Semi-Ozero Forestry Institution	Kalininsk (natural)	Birch	66	28	0,6	10B	25	10	0,6	III
52°27´59 .07´´N 64°19´20 .76´´E	12		Kalininsk (natural)	Aspen	50	3	1,1	8OC 2B	30 30	12 11	0,6	III
52°30´38 .52´´N 64°3´21. 89´´ E	13		Novonezhinsk (natural)	Fresh pine forests	7	5	0,7	10C	48	15	0,5	III

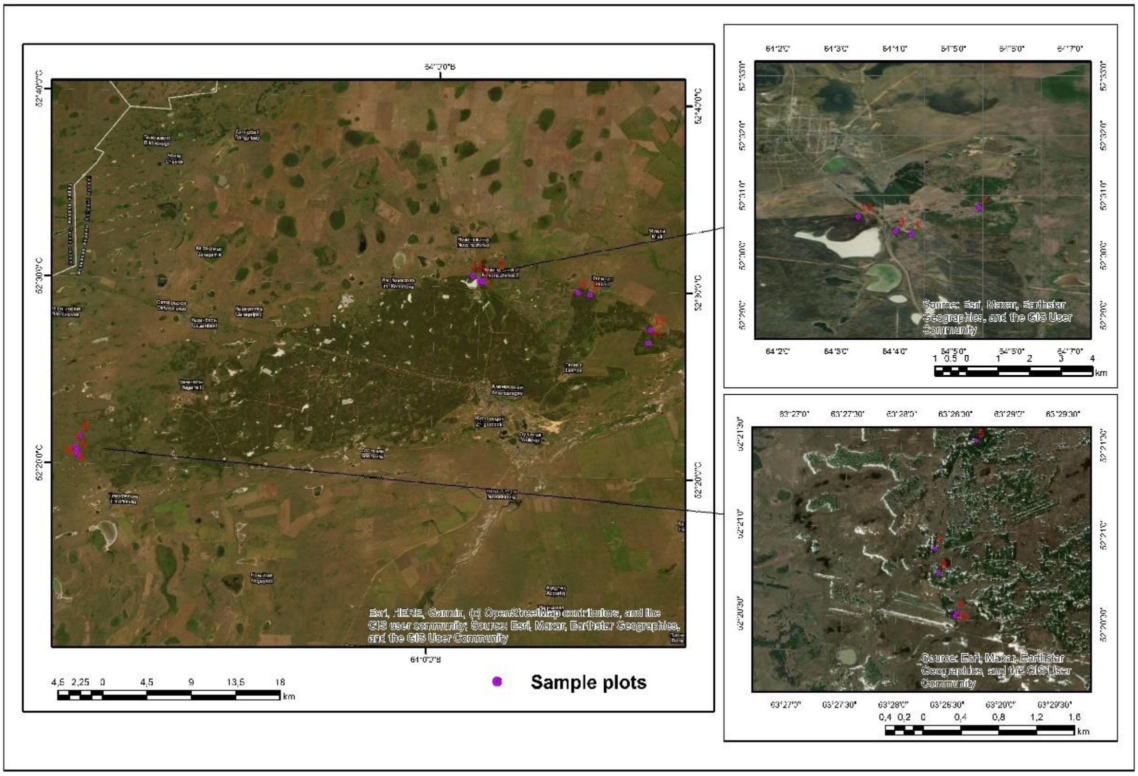

Fig. 3. Map of the Location of Forest Sample Plots.

Table 2.

Scoring Scale for Fire Resistance Factors of Forest-forming Species.

№	Factors of Fire Resistance in Pine Forests	Factor Values and Their Scoring			Weighting Coefficient
1	Average Tree Diameter, cm	>24/3	12 -24/2	<12/1	0,18
2	Average Distance to the Canopies, m	>10/3	5–10/2	<5/1	0,12
3	Average Depth of Root System, cm	>20/3	10–20/2	<10/1	0,12
4	Forest Fuel Reserve, t/ha	<30/3	30-60/2	>60/1	0,26
5	Number of saplings, thousand units/ha	<0,4/3	0,4-0,7/2	>0,7/1	0,05
6	Average height of saplings, m	<1/3	1-2/2	>2/1	0,16
7	Percentage of other species participation, %	>50/3	20 – 50/2	<20/1	0,11

The sum of the scores should be multiplied by their weight coefficients. The one-point interval corresponds to the minimum level of fire resistance, where all factors have a low degree of fire resistance and are rated one. The two-point interval corresponds to a medium level of fire resistance. The three-point interval corresponds to a high level of fire resistance. By dividing the scale into three intervals, we obtain numerical thresholds for each degree of fire resistance of forest-forming species: low fire resistance – the sum of weighted scores falls within the range of 1.00–1.50; medium – 1.51–2.00; and high – 2.01–3.00.

3. RESULTS

Field studies were conducted in 2023-2024 (**Figure 3**). A characteristic feature of the forest structure in the northern part of the country, based on diameter, is the predominance of thin trees. In the case of fires, thin trees die first, causing a significant portion of the trees to perish. When considering the stands as a collection of individual trees on sample plots (SP), the average diameter of the stand ranges from 14 cm to 28 cm. As a result, in the studied forests, the number of thin trees is twice as high compared to typical forests of Northern Kazakhstan.

When assessing the fire resistance of stands, the density and height of subordinate layers (understory, shrub layer, and the live ground cover) are important factors. Our observations have shown that the regeneration of forest-forming species, particularly pines, is generally sparse under the canopy of the stands. Due to this, there is no significant impact on the intensity of combustion and the speed of fire spread. With very low fire resistance, the regeneration perishes even during mild fires. The reserves of forest combustible materials play a significant role in assessing fire resistance. Information on these reserves is an essential condition for evaluating the forest fire properties of forest types, forecasting flammability, and designing fire prevention measures, which is especially important during high and extreme fire danger conditions due to weather conditions. Data on the reserves of forest combustible materials of forest-forming species in the study region are presented in **Table 3**.

Table 3.

Fire resistance of forest-forming species.

№	Average tree diameter, cm	Average distance to the crowns, m	Average root depth, cm	Forest fuel reserve, t/ha	Number of saplings, thousand pieces/ha	Average height of saplings, m	Proportion of other species, %	Fire resistance of forest-forming species
1	8C - 28 2B - 14	4,2 2,9	20 13	175,9 17,6	10,0	2,0	20 (deciduous)	tall
2	7C-16	0,6	2	18,9	-	-	-	low
3	8C - 16 2B - 14	3,7 1,7	12 15	110,0 12,2	0,5	2,0	20 (deciduous)	tall
4	10C - 18 +C - 22	3,6 4,3	18 15	184,0 10,2	-	-	-	average
5	10C - 20 +C 32	4,0 5,5	17	157,9 17,5	2,0	3,0	-	average
6	10C - 24	3,4	15	205,7	-	-	-	average
7	10C -20	3,2	14	117,3	-	-	-	average
8	10C -18	3,2	13	144,3	0,5	1,0	-	average
9	10C -20	3,4	16	142,5	-	-	-	average
10	10C -16	2,9	11	96,5	-	-	-	low
11	10B-10	2,2	8	49,8	-	-	-	low
12	8OC-12 2B-12	2,3 2,5	10 10	78,5 17,2	5	1,0	-	low
13	10C-10	2,9	11	58,2	4	1,0	10	average

The table shows that forest-forming species are characterized by increased total stocks of forest combustible materials, ranging from 18.9 t/ha in SP 6 to 205.7 t/ha in SP 6. The large reserves of forest combustible materials in the forests of the study region are due to the slow decomposition of organic matter in the conditions of a short summer. As a result, the processes of accumulation and decomposition of organic matter in northern conditions are balanced at a higher level. This explains the repeated predominance of the forest floor mass over the litter mass, as evidenced by the values of the litter-to-floor coefficient, which ranges from 10 to 48. This phenomenon is observed in all SPs and is characteristic of the pine island forests of the north. Significant reserves of organic matter lead to longer combustion times and slower fire front movement. As a result, the duration of direct thermal impact on trees increases, which causes more severe damage. In combination with the low fire resistance of larch, whose share in SPs 1 and 3 reaches 20%, this leads to the destruction of plantations after low- and even moderately weak surface fires.

SP № 2, top view

SP № 3

SP № 5, tree age determination

area adjacent to SP № 13, burned by fire in 2022

Fig. 4. Field work on sample plots.

According to the data in **Table 2**, the scales are based on the most significant factors affecting the fire resistance of plantations. The values of these factors are ranked for three fire resistance classes: high, medium, and low. The high fire resistance class applies to plantations where, in the event of a fire, tree loss would be up to 30%, the medium class applies to a loss of 31% to 70%, and the low class applies to a loss of 71% to 100%. Each factor corresponding to the high fire resistance class is assigned three points, the medium class receives two points, and the low class is assigned one point. According to our previous studies (https://www.pjoes.com/Evaluation-of-Natural-Fire-Hazard-Factors-nof-the-Forest-Area-in-the-Kostanay-Region,188254,0,2.html), these pine forests are classified as having a high natural fire hazard, which indicates the high adaptation of this species to fires at the plantation level.

Based on this information, calculations were performed to determine the fire resistance of pine forests (**Table 3**). The data show that as a result of these calculations, most of the pine forests in the Novonezhinsky forestry (SP 1, 3) of the Semiozernoye forest management are classified as highly fire-resistant. The pine forest on SP 1 is 90 years old and, consequently, has relatively large average tree diameter values. A similar situation is observed on SP 3 (stand age 60 years), where the values of these two most significant factors also exceed those of younger pine forests. A common feature of both SPs is their medium density (0.5), bonitet (III), and the stock per hectare (335 m^3). The distribution of the share of deciduous species (birch) in the stand composition at the level of 20%, combined with minimal undergrowth density, almost entirely eliminates the possibility of crown fires occurring. The high fire resistance of the pine forests in the Novonezhinsky forestry indicates a significant degree of adaptation of this species to fire at the plantation level. It reflects a certain level of fire resilience developed through the process of evolution. The high fire resistance of forest-steppe pine plantations suggests that this pyrogenic property of pine forests is one of the key factors ensuring their long-term existence.

It has been established that fresh pine forests without any share of deciduous species, with diameters ranging from 18 to 32 cm (SP 4-9), exhibit a medium degree of fire resistance. This indicates that even after a fire of moderate intensity, the expected tree loss could range from 30% to 70% or more of the total forest stock.

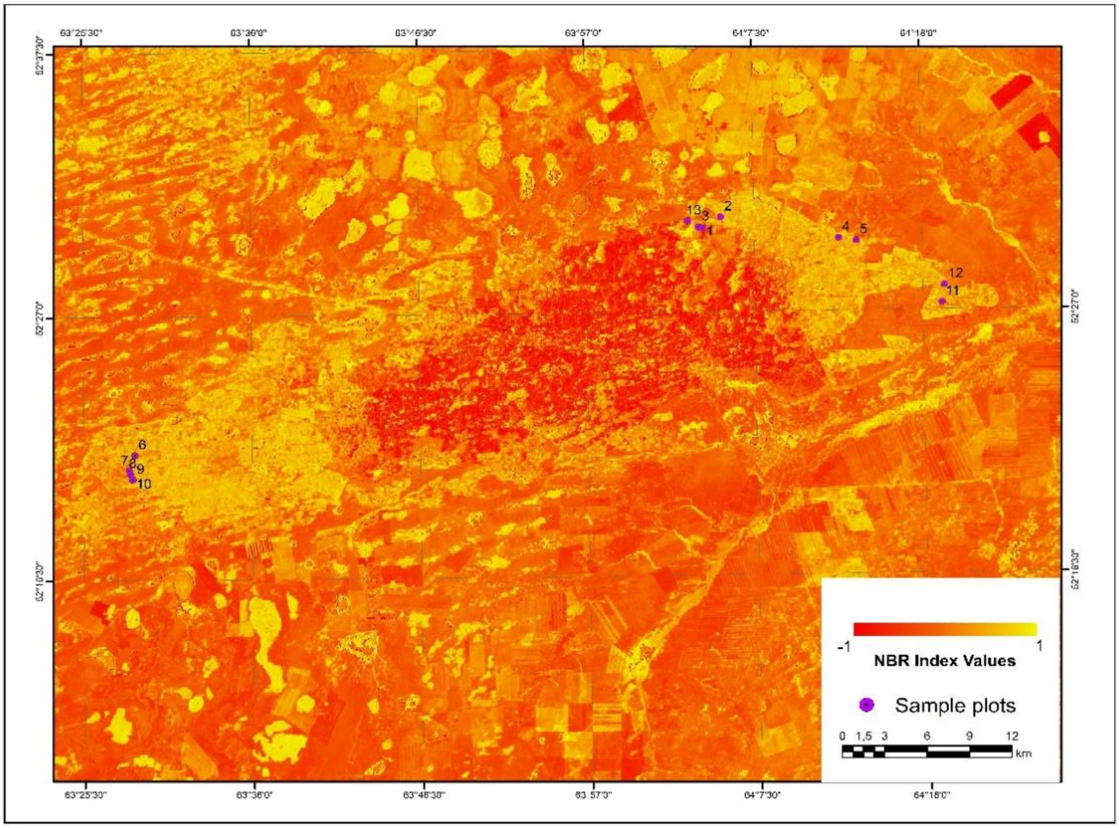

Fig. 5. The values of the normalized burn index.

The research data show that the pine forests of the Western Forestry of the Basman Forest Management, as well as the natural birch and aspen plantations of the Kalininsky Forestry, are generally characterized by a low degree of fire resistance. The pine forest on SP 7, which is 55 years old, also has relatively average values for the mean tree diameter. A similar situation is observed in SP 10 (stand age 46 years), where the values of these two most significant factors are also lower than those of more mature pine forests. The natural birch and aspen plantations on SPs 11 and 12, with diameters ranging from 10 to 16 cm and without the participation of other species, also exhibit a low degree of fire resistance. According to the results of our previous studies (https://www.pjoes.com/Evaluation-of-Natural-Fire-Hazard-Factors-nof-the-Forest-Area-in-the-Kostanay-Region,188254,0,2.html), these deciduous forests are classified as having a low natural fire hazard, indicating a poor adaptation of these species to fire at the forest stand level.

We found a weak negative correlation between the fire resistance of forest-forming species and the values of the normalized burn index (**Figures 5, 6**). The negative correlation between the fire resistance of forest-forming species and the normalized burn index values indicates that pine forests (SP № 1, 3), which are relatively fire-resistant, had the lowest fire intensity values.

On the area adjacent to SP 13 (**Figure 4**), which was affected by a crown fire of moderate intensity in 2022, the vegetation was completely destroyed by the fire, with no possibility of further growth. Field research shows that after the fire, natural regeneration is weak; overall, the undergrowth on this site was minimal even before the fire, with only a few young plants present (**Figure 7**). The weak regeneration is due to the high density of the mature stands, which hinder the growth and development of the undergrowth. The forest floor was completely consumed by the fire, and the soil seed bank was destroyed.

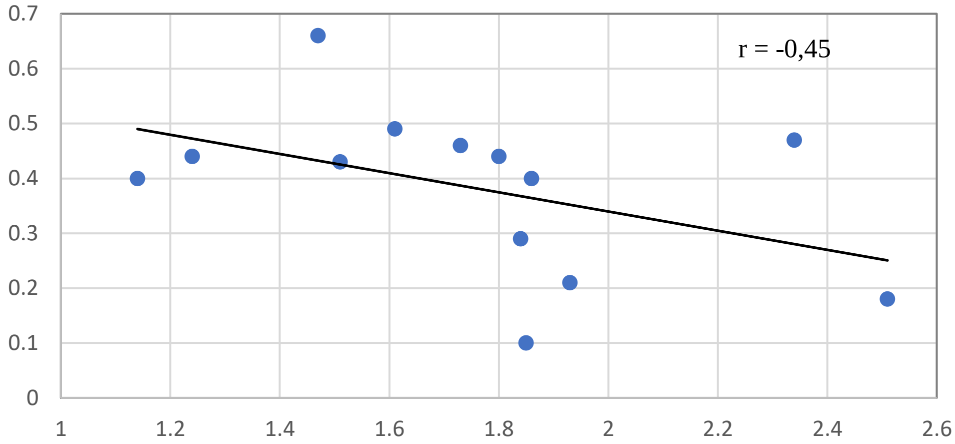

Fig. 6. Correlations between fire resistance and NBR values for forest-forming species across sample plots.

The process of natural recovery after the fire is uneven. The prolonged drought in 2022, which contributed to the rapid spread of the fire, also hindered natural regeneration in the forest over the past few years. The summer of 2023 was similarly dry, but by the end of the summer, prolonged rains began, which helped the uniform sprouting of common pine seedlings (**Figure 7).** The appearance of seedlings is due to the presence of undamaged, seed-bearing pine stands, known as seed trees. On average, there are about 1-2 seedlings per square meter, with some areas showing concentrated seedling growth, primarily in lowlands where moisture accumulates and in spots where the soil has been disturbed, promoting natural regeneration.

Fig. 7. Natural regeneration of pine.

The seed material that did not germinate in the spring began to sprout in large numbers in the fall, mainly in lowland areas where moisture retention is higher. During a field inspection of the fire sites, spring germination was also observed in areas where winter logging had taken place, particularly in spots where the trees had been skidded, which caused damage to the soil surface, thus allowing seeds to reach favorable, relatively prepared soils. For pine forests in this region, moisture—specifically its high level—plays a key role. The forest affected by the fire urgently requires the development and clearing of burn areas to prevent the spread of secondary stem pests and diseases. However, this increases the risk of damaging newly emerged pine seedlings during mechanized work.

4. CONCLUSION

The fire resistance of forest-forming species, as a pyrogenic property, is a relatively stable indicator, as it is primarily determined by the morphological structure, which remains relatively unchanged. Fire resistance is a cenotic form of species' resilience to the impact of forest fires. It is determined by the individual fire resistance of the plants within the community, the structural characteristics of the community (vertical stratification and horizontal heterogeneity of the phytocenosis), as well as the density and closure of the layers. The low fire resistance of larch on SPs 11 and 12 leads to the low fire resistance of the plantations. This indicates a weak adaptation of this species to fire at the plantation level, which is also a regional characteristic. Therefore, it is justified to consider that the fire resistance of plantations, developed through the process of phylocenogenesis, is largely determined by geographical location and represents a historical and biogeographical phenomenon. The results of the fire resistance assessment of forest-forming species allow for the planning and implementation of a range of forestry and fire prevention measures aimed at increasing the resilience of forest stands to fire. The creation and formation of fire-resistant plantations involve a comprehensive system of silvicultural, forest management, and fire prevention activities. Methods for increasing fire resistance should be based on targeted control of factors that determine the potential damage to plantations in the event of a high-intensity fire.

To prevent significant tree destruction in the event of a fire, priority measures must be taken in plantations with medium and low fire resistance. One such measure is thinning, which helps increase the fire resistance of plantations by raising the proportion of coniferous and deciduous species, as well as increasing the average diameter of the main species. To reduce the number of combustible materials, preventive burning can be conducted, following the controlled burning techniques and fire safety regulations in the forests of the Kostanay region. Thus, the fire resistance of plantations is determined by the interaction of numerous factors. The most important of these are the reserves of combustible materials, which influence the ignition strength and combustion intensity, as well as the tree diameter, which protects trees from thermal effects, characterizing their fire resistance. It should be noted that it is the combination of these indicators that can most objectively reflect the fire resistance of the stands. At the same time, we aimed to minimize the number of indicators used, believing that an increase in their number might lead to excessive "information noise." For this reason, we avoided using interrelated variables, preferring the one that most accurately characterizes the process under consideration. The selected indicators for assessing the fire resistance of forest-forming species are universal in nature: they can be used to study the fire resistance of forests in other regions, and the indicators can also be supplemented considering local specificities. The author is fully aware that the proposed fire resistance assessment system is just one of the possible practical approaches, and its implementation will require the development of specific forestry and fire prevention measures aimed at increasing the resilience of forest landscapes to fire impact.

A summary of the conclusions in the form of four main ideas is presented below.

1. Fire resistance is a synotic form of a species' resilience to the impact of forest fires. It characterizes the resilience of the entire stand or phytocoenosis to the pyrogenic factor. Fire resistance is determined by the individual fire resistance of the species within the coenosis, as well as the structural characteristics of the plant community, including vertical stratification and horizontal heterogeneity of the phytocoenosis, density, and canopy closure.
2. The pine forests of the study region are characterized by a high natural fire hazard and high fire resistance. In this context, it is reasonable to assume that the fire resistance of pine stands is largely determined by their geographical location. Therefore, it can be argued that the fire resistance of these stands is a biogeographical phenomenon.
3. The low fire resistance of larch stands in the forests of the study region indicates a weak adaptation of this species to fires at the stand level (phytocenosis).
4. The negative correlation between the fire resistance of forest-forming species and the values of the normalized burn ratio (NBR) indicates that pine forests, which are relatively fire-resistant, had the lowest values of fire intensity. These results suggest that the set of fire resistance factors used in this study can be applied to predict the consequences of fires at a regional scale.

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