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## POST-FIRE CONDITION AND RESTORATION OF FORESTS ON THE TERRITORY OF KOSTANAY REGION

The results of field studies of post-fire condition and reforestation of Kostanay region are presented. The purpose of the research is to study and analyze the post-fire condition and forest regeneration in the territory of Kostanay region. It was established that the magnitude of post-fire tree declines and their radial growth in stands of the main forest-forming species are determined by the type and intensity of fire. Taking into account the types of forest landscapes using space images, we have identified 7 key and control (background) sites that characterize the disturbed and background undisturbed forest cover. Among them, the most affected by the forest fire are key areas №5 and №7, where a top fire of medium intensity occurred. The forest litter of these key areas was completely burned in a severe fire, the soil seed stock was destroyed, and low intensity of natural regeneration is expected. The average grade of all studied key sites is estimated by us as III and it is connected with untimely harvesting, which resulted in the reduction of annual growth of the plantation. Sanitary condition of plantations in key sites №1, №5, №7 is unsatisfactory in comparison with other sites. Soils of the investigated key sites are not compacted and favorable for growth. In key plot No.1 there was a compacted crust in the surface soil layer. Uneven natural regeneration of common pine after the fire is observed. Predominantly friendly seed sprouting is associated with more moistened lowlands and loosened soil areas. Factors impeding the natural renewal of pine forests include deep burning of the forest floor and soil cover, mechanical effects on the soil and seedlings of the equipment used to develop harems, the mushroom wavy rhizina (*Rhizina undulata*) which affects the roots of coniferous trees.

**Key words:** forest, post-fire condition, forest restoration, key site, sanitary condition of trees, Kostanay region.

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### Қостанай облысының аумағындағы өрттен кейінгі жағдай және ормандарды қалпына келтіру

Қостанай облысының өрттен кейінгі жағдайы мен орманды қалпына келтірудің далалық зерттеулерінің нәтижелері ұсынылды. Зерттеу мақсаты Қостанай облысының аумағындағы өрттен кейінгі жағдайды және ормандарды қалпына келтіруді зерделеу және талдау. Ағаштардың өрттен кейінгі құлауы және олардың негізгі орман құраушы алқап ретіндегі радиалды өсуі өрттің түрі мен қарқындылығымен айқындалатыны анықталды. Орман ландшафттарының түрлерін ескере отырып, ғарыштық суреттер арқылы біз бұзылған және фондық бұзылмаған орман жамылғыларын сипаттайтын 7 негізгі және бақылау (фондық) учаскелерін анықтадық. Олардың ішінде орман өртінен ең көп зардап шеккендер – №5 және №7 негізгі учаскелер, себебі, онда орташа қарқындылықтағы жоғарыдағы өрт болған. Осы негізгі учаскелердің орман төсемі қатты өртте толығымен өртенді, тұқымның топырақ қоры жойылды, табиғи жаңарудың төмен қарқындылығы күтілуде. Барлық зерттелген негізгі учаскелердің орташа бониттен біз III деп бағалаймыз және бұл уақтылы ағаштарды кеспеге байланысты, осы себеп алқаптардың жылдық өсуінің төмендеуіне әкеп соқтырды. №1, №5, №7 негізгі учаскелердегі алқаптардың санитарлық жағдайы қалған учаскелермен салыстырғанда қанағаттанарлықсыз. Зерттелген негізгі учаскелердің топырақтары тығыздалмаған және өсуге қолайлы. №1 негізгі учаскеде

топырақтың беткі қабатында тығыздалған қыртыс байқалды. Өрттен кейін кәдімгі қарағайдың біркелкі емес табиғи жаңаруы байқалады. Негізінен достық тұқым көшеттері ылғалданған ойпаттармен және топырақтың қопсылған жерлерімен байланысты. Қарағайлы ормандардың табиғи жаңаруына кедергі келтіретін факторларға орман төсемі және жер жамылғысының терең күйіп кетуі, топыраққа механикалық әсер ету және көшеттер өртеу үшін қолданылатын техника, толқынды ризина саңырауқұлағы (*Rhizina undulata*) жатады, олар қылқан жапырақты ағаштардың тамырларын зақымдайды.

**Түйін сөздер:** орман, өрттен кейінгі жағдай, орманды қалпына келтіру, түйінді учаске, ағаштардың санитарлық жағдайы, Қостанай облысы.

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### Послепожарное состояние и восстановление лесов на территории Костанайской области

Представлены результаты полевых исследований послепожарного состояния и лесовосстановления Костанайской области. Цель исследования изучение и анализ послепожарного состояния и восстановления лесов на территории Костанайской области. Установлено, что величина послепожарного отпада деревьев и их радиальный прирост в насаждениях основных лесобразующих пород определяются видом и интенсивностью пожара. С учетом типов лесных ландшафтов с помощью космических изображений нами определены 7 ключевых и контрольных (фоновые) участков, которые характеризуют нарушенные и фоновые ненарушенные лесные покровы. Среди них наиболее пострадавшие от лесного пожара – это ключевые участки №5 и №7, где прошел верховой пожар средней интенсивности. Лесная подстилка данных ключевых участков при сильном пожаре сгорела полностью, почвенный запас семян был уничтожен, ожидается низкая интенсивность естественного возобновления. Средний бонитет всех изученных ключевых участков оценивается нами как III и связано это с несвоевременным проведением рубок ухода повлекшим к снижению годового роста насаждения. Санитарное состояние насаждения в ключевых участках №1, №5, №7 неудовлетворительное по сравнению с остальными участками. Почвы исследованных ключевых участков не уплотнены и благоприятны для произрастания. В ключевом участке №1 наблюдалась уплотненная корка в поверхностном почвенном слое. Наблюдается неравномерное естественное возобновление сосны обыкновенной после пожара. Преимущественно дружные всходы семян связаны с более увлажненными низинами и разрыхленными участками почв. К факторам препятствующим естественному возобновлению сосновых лесов относятся глубокое прогорание лесной подстилки и почвенного покрова, механическое воздействие на почву и сеянцы техники, используемой для разработки гарей, гриб волнистая ризина (*Rhizina undulata*) который поражает корни деревьев хвойных пород.

**Ключевые слова:** лес, послепожарное состояние, восстановление леса, ключевой участок, санитарное состояние деревьев, Костанайская область.

### Introduction

Forests are one of the most economically significant natural landscape formations on the planet, the formation and evolution of which is largely associated with the impact of the pyrogenic factor. They perform extremely important environment-forming and stabilizing functions, largely determining the ecological balance in the biosphere [1-3].

Forest fires are an eternal companion of forests, largely determining the current appearance of forest cover in vast areas. The role of fires is especially great in plantations of light coniferous tree species

(pine forests, larch forests), which due to their natural biological features are most exposed to fire loads. Here fires act as the leading and sometimes the only forest-forming factor, which, depending on the nature of fire impact, determines the degree of environmental transformation, composition and structure of forest communities, directions, rates of regenerative succession and dynamics of renewal processes [4-7].

Natural and climatic features of Kostanay region are determined by its inland location. Six of the seven key areas are located on the territory of the “Semiozero Forestry Institution” (Figure 1). The total area of the forestry institution is 62359

hectares. The forestry institution is structurally divided into four lesnichestvo – Novonezhinskoye, Kalininskoye, Amankaragai and Arkalykskoye. The

length of the territory of the forest establishment from north to south is 480 km, from west to east – 400 km [8].

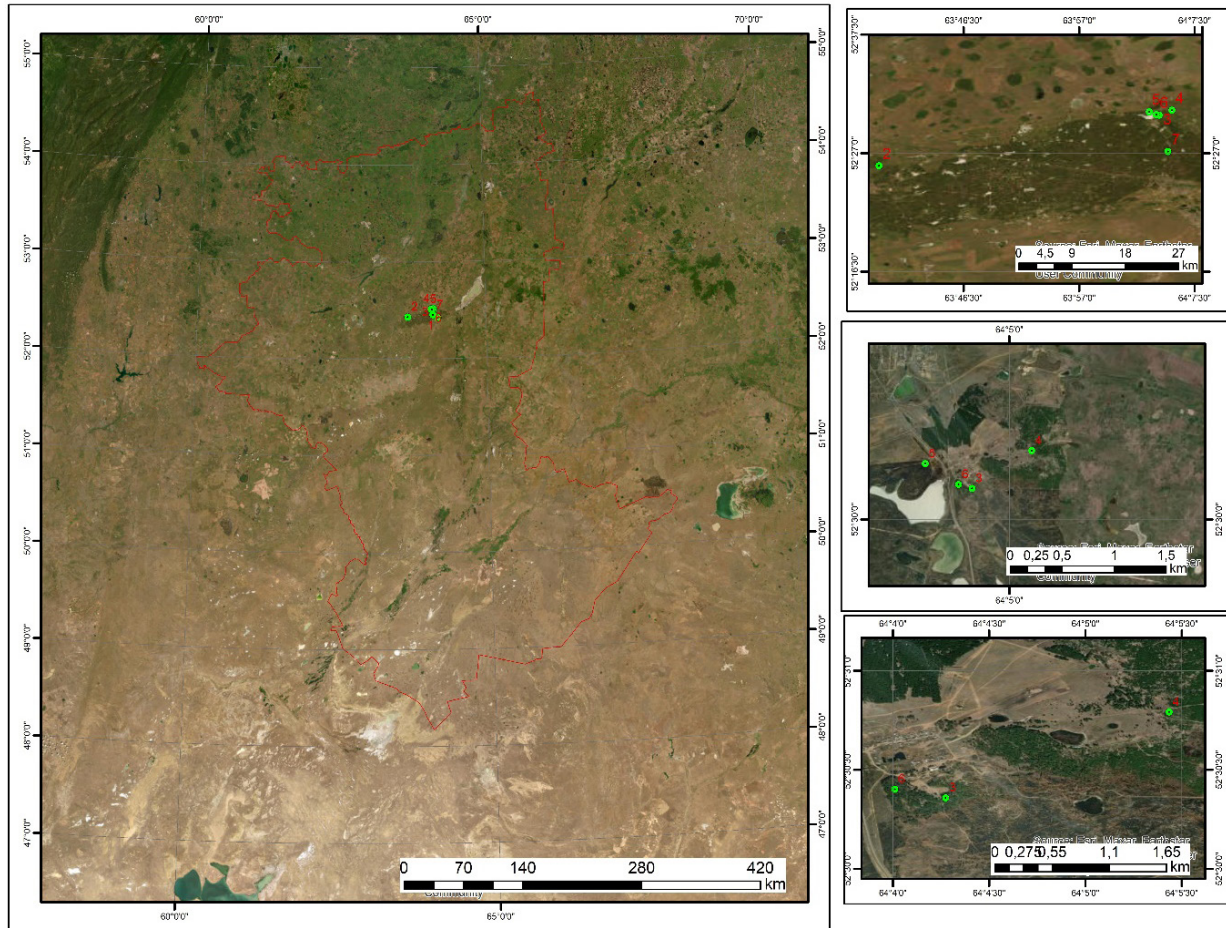


Figure 1 – Map of key areas of Kostanay region

The territory of key sites 1,3,4,5,6,7 belongs to the steppe zone, in the subzone of arid steppes. The area of steppe pine forests in the ancient Abugo-Tobolskaya trough of ancient runoff represents two sandy, north-eastward elongated, disconnected massifs within the boundaries of the northern half of the steppe landscape zone.

The main forest forming species is the common pine, other species are birch and aspen, bush willow, rose hips, tavalga forming both pure and mixed stands.

Forests are located only on ancient alluvial sands, along the tops of ancient dune ridges and upper parts of their slopes. Birch and aspen forests are confined to the lower parts of the slopes of sandy ridges and are often adjacent to the shores of salt lakes. Shrub willow, honeysuckle are confined to

the banks of rivers and lakes. Rosehip, tavalga grow along soyas and slopes.

On clearings and glades sandy forage steppes are formed. On the borders of the hog massifs there are characterized by not wide strips of meadow-solonchak vegetation.

Steppe vegetation is represented by St. John's woad (*Stípa pennáta*), Becker's tipczak (*Festuca beckeri*), bluebunch (*Koelēria glāuca*), Siberian honeysuckle (*Agropyron sibiricum* (Willd.) P. Beav. Beav.), wormwood (*Artemísia*). The cover of the southern part of the institution is represented mainly by wormwood-solanaceous and grass-wormwood vegetation.

The climate of the Semiozero Forestry, remote from large water areas, is sharply continental, with hot, dry summers and cold, low-snow winters. Low

winter and high summer temperatures combined with dry weather, dust storms, late spring and early fall frosts negatively affect the growth and development of tree and shrub vegetation. Favorable climate factors include a large abundance of solar radiation and a rather long frost-free period.

Unfavorable climatic factors of the region are droughts, dry winds, strong winds, dust storms, late spring and early autumn frosts, severe frosts in winter, snow blizzards and low precipitation, increasing aridity to the south, high evaporation rate. The combination of high temperature, low humidity, and high wind speeds determine atmospheric droughts, which cause a decrease in soil moisture reserves to a level unavailable to plants. The cumulative effect of drought is expressed first of all in the reduction of growth processes in tree and shrub vegetation and forest crops, which in case of a long dry period can lead to the death of plants. The existing distribution of pine, birch, aspen and various shrub plantations follows quite naturally from the peculiarities of climatic factors of the forest area. The relief of the territory where the key areas are located is rather complex, its origin is connected with alluvial and subsequent aeolian processes. Aeolian relief forms alternate with gentle sandy ridges and lower sloping hills with small hollows between them. Meadow-steppe plains form a winding network of arms among the elevated hilly sands. In some places, especially in lower parts along hillocks and ramparts, they have the character of floodplain meadows, flooded in spring by melt water and sometimes swamped.

Soil-geographical zoning most fully reflects the peculiarities of the natural environment of individual regions and districts, because in addition to the features of relief, climate and water regime, it also takes into account the nature of the soil cover of the territory. Climate, relief, parent rock, flora and fauna, as well as human activity have a great influence on the intensity and diversity of soil formation processes. According to soil zoning, the area of the institution location is referred to the subzone of chestnut, brown soils. Soil-forming rocks are white sands, sandy loam, loams, loams, which lie on pistachio clays. On the tops of high sandy hillocks and parts of slopes, where groundwater is deeper than 7 meters from the surface, soils are not soaked and are represented by soddy-sandy varieties. In closed depressions, under pine islands, malt, meadow and meadow-chestnut soils develop. On low sandy outbursts, in hollows and more extensive depressions among sands, soils are characterized by leaching type of moistening. Podzolistogley and peat-gley soils are formed under conditions of high groundwater table and constant

sufficient moistening. On meadow-steppe areas, near hollows, depending on hydrological regime and depth of underlying saline rocks saline soils of hydromorphic series were formed to different degrees [8].

The following soils were identified in the study area: sod-pine soils; brown forest secondary-odder soils; gray forest soils; dark-gray saline soils; solody ogleenye soils; solodyzabolozochnye solonetsye soils.

Forest fires from 2001 to 2019. According to the forest fire zoning, the territory of the forest establishment is referred to the Amankaragai forest fire district with the duration of the fire-dangerous period of 208 days. In the past audit period (18) on the territory of the forestry institution 88 cases of forest fires were registered, covering 5249.9 hectares of the total area, including forested lands – 5010.7 hectares, represented by plantations and forest crops. The main reasons of occurrence of lower forest fires were: thunderstorms – 53 %, careless handling with fire (through the fault of the population) – 22 %, unidentified – 16 %, arson – 7 % and from steppe fires, and from short-circuiting of electric wires – 2 %. According to the data of the forestry institution the root stock of burnt and damaged wood amounted to 660.07 thousand m<sup>3</sup>. The average area of forest fire amounted to 59.6 ha [8].

The large forest fire that occurred in September 2022 is worth noting separately, as the fire covered a huge area, and such a fire has not been recorded for the last 30 years. The fire covered 29,392.4 hectares, including forested area of 24,919.4 hectares.

*Basaman forestry is located* on the territory of Auliekol administrative district. The total area of the forestry institution is 44,898 ha. The forestry institution is structurally divided into four lesnichestvo – Kazanbas, Western and Kondratievskoye.

The length of the territory of the forest institution is from north to south – 48 km, from west to east – 35 km [9].

The territory of the Turgai depression within the modern borders of Kustanay oblast, which includes the territory of the forestry institution, is characterized by peculiar natural conditions, determined by its inland position and significant extent from north to south. The large length of the territory in meridional direction creates here a consistent change of landscapes: forest-steppes in the northern areas, steppes in the central part of the region and semi-deserts in the south. The territory of the Basamansky forestry institution, located in the northern part of the Turgai depression, belongs to

the steppe zone in the subzone of moderately arid steppes.

The area of steppe pine forests in the ancient Abugo-Tobolskaya trough of ancient runoff is two sandy, north-eastwardly elongated, disconnected massifs within the borders of the northern half of the steppe landscape zone.

The main forest forming species is common pine, other species are birch and aspen, forming both pure and mixed plantations.

Forests are located only on ancient alluvial sands, on the tops of ancient dune ridges and upper parts of their slopes. Birch and aspen-birch forests are confined to the lower parts of the slopes of sand ridges and are often adjacent to the shores of salt lakes – sorrows. On clearings and glades sandy-hemlock steppes are formed. Not wide strips of meadow-solonchak vegetation are characteristic for hog massifs along their borders.

Steppe vegetation is represented by *Stípa pennáta*, *Festuca beckeri*, *Koelēria glāuca* and others. These grasses occur under the canopy of sparse forest.

The climate of the forest, located in the center of the continent far removed from large water areas, is sharply continental with hot, dry summers and cold, low-snow winters.

Low winter and high summer temperatures combined with dry weather, dust storms, late spring and early fall frosts have a negative impact on the growth and development of forest vegetation and make it difficult to introduce introductions into plantations.

The main types of soils in the study area are as follows. Turf-hog soils. Brown forest secondary – sod. Gray forest soils. Dark gray silty soils. Solody.

During 1999-2019 on the territory of Basamansky forest institution 147 cases of top and bottom forest fires were registered, covering 4275.8 ha of the total area, including forested lands – 2392.7 ha, represented by pine and birch plantations. The root stock of burnt and damaged wood amounted to 107.7 thousand m<sup>3</sup>. Causes of forest fires were mainly caused by lightning.

The smallest area registered in the Book of forest fires is 0.06 ha, the largest – 1941.7 ha (2010), in Kazanbas and Western lesnichestvos.

The average annual number of forest fires for the last 5 years is 24 cases on the area of 679.7 ha. Out of 147 cases of fires 122 are lowland fires, 25 are highland fires. The average area of one fire is 29 ha [9].

As a result of a large forest fire that occurred in September 2022 in Basamansky forestry institution,

the fire covered – 10,380 hectares, including forested area – 7,473.9 hectares.

The purpose of the research is to study and analyze the post-fire condition and restoration of forests on the territory of Kostanay region.

### Materials and methods of research

The objects of the study were forest areas of Kostanay region: seven key sites in Semiozerny and Basamansky forestry institutions (Table 1).

Sample plots and data of their binding to the quarterly network, their geographical coordinates and altitude were determined, as well as the characteristics of the terrain, soil and ground conditions, and all forest components were described.

The location of the sample area was selected in a part of the plot, homogeneous in all taxonomic indicators and growing conditions, not closer than 30 m from a plot of another category. The size of the sample area was determined by the need to have at least 200 trees of the main forest element.

UAV imagery to track the dynamics of natural processes and assess the impact of fire in the forest.

Long-term unburned areas of forest or disturbed forest land (clearcuts, burned areas) were used as control plots. The correspondence of the fire-treated plots to the control plots was ensured by their belonging to the same type of habitat conditions, identity of relief and soils, similarity of species composition, pre-fire completeness and age of stands; for disturbed plots – by the age of cutting and previous fire.

To characterize the key areas, a field study form is developed, which specifies the forest institution, lesnichestvo, quarter, subdivision, area and protection category. Then the area of the key plot and land category are studied. The soil type of the key plot is determined and soil density is determined using a Wile SOIL soil density meter, as a decrease in organic matter and physical clay content after fire leads to an increase in soil density. Undergrowth is counted to determine the dynamics of natural regeneration.

Stand bonitet, weighted average sanitary condition score, and fire type are determined. All trees with a diameter at a height of 1.3 m greater than or equal to 4 cm were counted. Tree diameter, height, tree species, maximum canopy height, minimum canopy height, trunk temperature, wood moisture, proportion of crown shrinkage due to lowland fires (%), percentage of crown damage (by high or severe lowland fire), and condition category were determined. A tree was included in the enumeration if the center of its trunk was within the boundary of the sample area.

**Table 1** – Data on key sites

№ of key site	Names of forestry	Name of le-snichestvo	Coordinates	Forest block number	Forest allotment number	Date	Tree species	Soil
						time	№ of samples	№ of samples
1	Semiozerno-ye	Kalininsky	52°25'14.70'' N 64°10'11.59'' E	107	1	20.09.2023 г. 10:15	Pine bark (cinders)	Envelope
2	Basamans-koye	Western	52°25'52.55'' N 63°38'48.83'' E	3	22	21.09.2023 г. 09:40	2022 г	Envelope
3	Semiozerno-ye	Novonezhin-skoye	52°30'21.46'' N 64°4'16.48'' E	20	1	22-23.09.2023 г. 10:00	Pine bark (cinders)	Envelope
4	Semiozerno-ye	Novonezhin-skoye	52°30'47.54'' N 64°5'26.08'' E	9	11	24-25.09.2023 г. 08:20	2022 г	Envelope
5	Semiozerno-ye	Novonezhin-skoye	52°30'38.52'' N 64°3'21.89'' E	7	5	26.09.2023 г. 09:15	Pine bark (background)	Shurf 5.1 0-5 sm 5.2 5-20 sm 5.3 20-60 sm
6	Semiozerno-ye	Novonezhin-skoye	52°30'24.12'' N 64°4'0.61'' E	7	22	27.09.2023 г. 07:35	Pine	Shurf 6.1 0-20 sm 6.2 20-40 cm 6.3 40-60 sm 6.3 60-80 sm
7	Semiozerno-ye	Kalininsky	52°27'9.06'' N 64°5'3.56'' E	54	27	28.09.2023 г. 08:00	ash 2004	Envelope

The depth of burning was assessed visually by examining the root necks and assessing the degree of destruction of litter remaining after the fire, and then comparing this data with the situation typical for the same unburned area.

Fire type, form and severity were determined by stand condition, including the extent of crown damage and desiccation, height of char on trunks, burned crust (bark) and root feet, and the extent of burned ground cover, old stumps and deadwood. The number of years since the fire and inter-fire intervals were determined from trunk cuttings with fire dried stumps and from stumps of cut dead trees. The age and condition of the undergrowth were used to determine the age of the fire.

Forest-typological description of sample areas, assessment of sanitary condition, determination of fire class, and taxation of stands were carried out in accordance with generally accepted methods.

All trees with a diameter at a height of 1.3 m greater than or equal to 4 cm were counted. The

diameter, height, tree species, maximum canopy height, minimum canopy height, proportion of shrunken crowns as a result of lowland fires (%), and percentage of crown damage (in case of high or strong lowland fires) were determined. A tree was included in the enumeration if the center of its trunk was within the boundary of the sample area.

In patches with small trees (most of them 10 cm in diameter), 20×20 m plots were laid out to count them, and the maximum and minimum diameter and average height were determined.

A typical sampling method of observation was used to survey intact areas. Sample plots were selected in fire-affected stands and in control plots that had not been exposed to fire for a long time.

The age of the main forest element was determined by counting the number of annual layers on cores taken with an age drill at the root neck or on stumps from 3-5 felled trees. The age of other forest elements was determined by eye, if necessary, on 1-3 felled model trees or with the help of an age

drill. Diameter was measured with a measuring fork at a height of 1.3 m, height with an electronic altimeter, moisture with a wood moisture meter, and temperature with a pyrometer.

Sampling of soils and vegetation for laboratory studies of soil properties and composition to study changes after fires. Study of changes in the chemical composition of soils compared to background soils. Study of changes in chemical composition of tree bark compared to bark of trees not exposed to wildfire.

In the test areas, the description and accounting of undergrowth and self-seeding were carried out on the accounting sites, while the amount of preserved and post-fire undergrowth was calculated in accordance with the recommendations of A.I. Buzykin and A.V. Pobedinsky.

The description and accounting of undergrowth and self-seeded trees was carried out on the sample plots, and the amount of preserved and post-fire undergrowth was counted in accordance with the recommendations of A.I. Buzykin and A.V. Pobedinsky.

Determination of type, composition, completeness, bonitet according to the table of M.M. Orlov, age, average height of forest plantations, as well as the stock per hectare and on an allotment before the fire with the help of sample plots and according to the forest inventory data.

To record and characterize undergrowth and undergrowth within the trial area, at least 10 test plots (representing about 0.25-2.0% of its area) of square shape of 2×2 m or 1×1 m (in case of dense distribution) were laid out. In case of uniform undergrowth distribution, the plots were laid uniformly over the

area. In sample plots with clumps of undergrowth, the percentage of area occupied by clumps or groups was determined; the undergrowth was counted separately for each placement category. The number of undergrowth on average per 1 ha was determined taking into account areas occupied by clumps and areas with evenly spaced undergrowth. Undergrowth was counted in 5 height groups: up to 0.10 m; 0.11-0.25 m; 0.26-0.50 m; 0.51-2.0 m; more than 2.0 m. According to its condition, it was subdivided into reliable, doubtful and shrunken. Specimens with axial shoot growth exceeding the growth of neighboring lateral shoots, with green needles (leaves), without mechanical damage, free of phyto-diseases, and free of entomological pests were considered as reliable. For each height group, the average age of the undergrowth was determined by counting the number of annual layers or whorls in 5 average specimens. Undergrowth was noted in relation to micro- and nano-relief elements, to the degree of ground cover burning, species composition of living ground cover, canopy closure or other forest features. At the sites we counted undergrowth by species, determined average height and density.

Determination of forest sanitary condition. At least 200 trees were counted on the sample plots, their enumeration was carried out, diameter was measured with a measuring fork at a height of 1.3 m, and height was measured with an electronic altimeter. During the enumeration, trees are divided into categories of sanitary condition. The sanitary condition of trees is determined according to the scale in force in Kazakhstan, according to Annex 20 to the Rules of forest felling in the areas of the state forest fund [10]. Table 2.

**Table 2** – Scale of sanitary condition of trees [10]

Category Score	Signs of tree condition by species	
	Conifers	Deciduous
I – no signs of weakening	The crown is dense, needles are green, no desiccation, no damage	Crown dense, foliage green, no drying, no damage
II – weakened	Crown weakly openwork; needles green, light green or scorched (burnt) not more than 1/3; drying of some branches, damage to some root paws, local damage to trunk.	Crown slightly openworked; foliage falls off early or is eaten by 25%; individual branches withered; localized damage to trunk and root paws; sporadic water shoots
III – severely weakened	Crown strongly openworked; needles light green or gray or matt, or eaten off (burnt) up to 2/3, very weak growth, desiccation of up to 2/3 of the crown, damage to root paws or trunk, ringing them up to 2/3; attempts of settlement of trunk pests; fruiting bodies of fungi or other signs of severe trunk damage.	Crown strongly openworked; foliage very small, light colored, early yellowing and falling off, very weak or no growth; up to 2/3 of crown withered; trunk and root paws damaged on 2/3 of circumference; sap flow on trunks and skeletal limbs; attempted or localized dispersal of trunk pests; abundant water shoots; fruiting bodies of fungi on trunk

Category Score	Signs of tree condition by species	
	Conifers	Deciduous
IV – withered	Crown strongly openworked; needles gray, yellowish or yellow-green, falling off, very weak or no growth; drying of more than 2/3 of branches; damage to trunk and root paws more than 2/3 of circumference; signs of settlement by stem pests	More than 2/3 of crown withered or shriveled; more than 2/3 of trunk circumference and root feet damaged; signs of stem pest infestation; shriveled water shoots
V – fresh deadwood (current year)	Gray, yellow or brown, partially crumbling needles, partial bark fall, signs of infestation or flight of stem pests.	Leaves shriveled, wilted or absent; partial loss of bark; signs of infestation or stem pests.
VI – old deadwood (of previous years)	No needles; bark and small twigs partially or completely fallen off; flight holes of stem pests; fungus of wood-destroying fungi under the bark	Leaves absent; bark and small twigs partially or completely fall off; flight holes for stem pests; under bark fungus of tree-destroying fungi.

The weighted average sanitary condition score by number of trees (Bg) was determined by the formula:

$$Bg = \frac{z1n1+z2n2+z3n3+z4n4+z5n5+z6n6}{n1+n2+n3+n4+n5+n6}$$

where,

$z1 \dots z6$  – tree condition categories 1 to 6;

$n1 \dots n6$  – number of trees in the sample area with the corresponding condition category, pcs.

Sanitary condition was assessed according to the generally accepted scale (Table 3) [11, 12].

**Table 3** – Assessment of stand condition depending on the value of weighted average condition score

Value of weighted average score	Sanitary condition of forest stands
1,0-1,5	Healthy
1,6-2,5	Weakened
2,6-3,5	Severely weakened
3,6-4,5	Shriveling
4,6- and more	Withered

Signs of damage or burning of trees, their separate parts and various components of biocenosis were determined according to the approved rules of accounting, determination and compensation for damage caused by fires in the forest fund [12].

Filming was carried out with DJI Mavic 3 Pro Fly More Combo + DJI RC. Photo and video footage obtained by drones, both by conventional and special cameras, provides a complete picture of forest areas and their condition, including information on tree species and heights and their

exact location in accordance with GPS coordinates, which is certainly necessary for effective and sustainable forest management. In the course of analyzing the obtained images, fire boundaries were specified for a number of key observation points located in different landscape-forming conditions.

The cameral stage includes processing of the collected materials, laboratory studies of soils, tree bark, structuring of information, and preparation of reports.

### Results of field studies

The key site № 1 is located in subdivision 1 of quarter 107 of Kalininsky lesnichestvo of Semiozerny forestry institution. The area of the forest section is 9.2 hectares, according to the category of protection this forest area belongs to the field – and soil-protective forests, there are artificial plantations, i.e. forest cultures, which are 56 years old. The average height of plantations is 14 meters, and the average trunk diameter at a height of 1.3 meters is 16 centimeters. In this area, the main forest forming species is common pine. The growing stands belong to the III bonitet. Average weighted score of sanitary condition is 5. Soil type is chestnut soils with density index 150 on the instrument dial 0-14 cm/kg<sup>2</sup>, i.e. favorable conditions for growth.

According to the last forest inventory conducted in 2019, the completeness of plantations is 0.7 and the average wood stock is 165 m<sup>3</sup> per hectare, that is, on this allotment before the fire the wood stock was 1518 m<sup>3</sup> [8].

This site was selected as one of the key sites due to the fact that in this area trees were massively fallen, broken off at a height of 2.5 – 3.5 meters and scattered in two opposite directions, as a result of



the so-called “explosion”, which occurred due to the oncoming flames (Figure 2).

The type of fire is defined as riding of medium intensity [13]. Soil and bark samples of damaged wood were taken at this site in order to determine the chemical composition and changes after the fire. The top layer of the soil is slightly compacted at a thickness of 5 cm.

As a result of heavy rainfall, from August 30 to September 20, 2023, a process of natural renewal

is observed, that is, seedlings (self-seeding) of ordinary pine aged 20-30 days. The appearance of seedlings is due to the presence of intact fruiting pine plantations, the so-called testes. On average, there are about 1-2 seedlings per 1 m<sup>2</sup>, and there are also separate areas where there is an accumulation of seeds, mainly lowlands with accumulation of moisture and places where there is a soil injury that promotes natural regeneration (Figure 3).



**Figure 2** – Key area 1. Massive tree fall



**Figure 3** – Key area 1. Natural renewal of pine

The wavy rhizina mushroom (*Rhizina undulata*), characteristic of scorched soils, campfires and harems, is found. The wavy rhizina fungus (*Rhizina undulata*) can infect the roots of coniferous trees, which are 20-50 years old, which is an unfavorable factor for seedlings. Coniferous trees are mainly affected by wavy rhizina (*Rhizina undulata*), whereas the roots of deciduous trees are not affected by the wavy rhizina mushroom (*Rhizina undulata*) (Figure 4).

No sampling plots were laid to determine the sanitary condition of plantations due to the absence of trees growing on the root.

This key area is littered with fallen trees, some of which are in non-lethal condition. Natural regeneration is due to undamaged seedlings and abundant precipitation. Undergrowth accumulation is associated with lowlands and moisture accumulation.

Key site No. 2 is located in subdivision 22 of quarter 3 of the Western forestry block of the Basaman Forestry Institution. The area of the forest section is 5.3 hectares, according to the category of protection this forest area belongs to the field – and soil-protective forests, where there are artificial plantations, i.e. forest cultures, the age of which is 44 years. The average height of plantations is 12 meters, and the average trunk diameter at a height of 1.3 meters is 14 centimeters. In this area, the main forest forming species is common pine. The growing stands belong to the III bonitet. At this site, the minimum height of soot is 1.0 m, and the maximum height of soot is 4.0 meters. According to the results of reconnaissance survey the main number of trees belongs to the IV category of tree sanitary condition. Soil type is hog sand with density index of 100 on the dial of Wile Soil density meter, i.e. from 0-14 cm/kg<sup>2</sup>, which is favorable conditions for growth.



**Figure 4** – Key site 1. *Rhizina undulata*

According to the latest forest inventory, conducted in 2019, the completeness of plantations is 0.7, and the average wood stock is 134 m<sup>3</sup> per hectare, that is, on this section before the fire the wood stock was 710.2 m<sup>3</sup> [8].

This site was selected as one of the key sites due to the fact that the main species here is pine as a forest crop, which is more susceptible to forest fires compared to natural stands.

A sample plot of 0.2 hectares was established at this site, where a complete enumeration of trees was carried out to determine the sanitary condition and taxation characteristics of trees.

The age of the crops is classified as middle-aged. This plot serves as a determinant of the flammability of forests of this category at the specified completeness and forest type. And also the uniqueness of this plot is that it is located at the forest edge and has different degrees of fire damage (Figure 5).

The type of fire was determined to be a lowland runaway fire of moderate to severe intensity. In this plot, a sample area was established and a complete census was conducted to determine the sanitary condition of trees, and soil and bark samples of damaged wood were taken.



**Figure 5** – Key area 2 top view

At this site, the fire did not fully cover the key area in medium-aged pine stands. There are completely burned trees, live ground cover, and small areas where there was a downward runaway fire of medium intensity, which slightly damaged the thick bark of trees. There is also a forest edge not damaged by fire.

In this key area there are old-growth forest crops, which prevent the growth of self-sown trees of natural origin, but after the fire, as a result of the cessation of growth of individual trees, self-sown pine trees appeared en masse.

Key site No. 3 is located in section 1 of quarter 20 of the Novonezhinskoye lesnichestvo of the Semiozero forestry institution. The area of the forest section is 9.2 hectares, according to the category of protection this forest area belongs to the field – and soil-protective forests, there are natural forest plantations, the age of which is 93 years. The average height of plantations is 21 meters, and the average trunk diameter at a height of 1.3 meters is 28 centimeters. The main forest-forming species in this area is the common pine. The growing stands belong to the III bonitet. According to the results of reconnaissance survey the main number of trees belongs to II and III categories of tree sanitary condition. Soil type is hog sand with density index 100 on the dial of Wile Soil density meter, i.e. from 0-14 cm/kg<sup>2</sup>, which is favorable conditions for growth.

According to the latest forest inventory conducted in 2019, the plantation completeness is 0.5 and the average timber stock is 195 m<sup>3</sup> per hectare, which means that this allotment had a timber stock of 1794 m<sup>3</sup> before the fire [8].

This plot was selected as a background (control) undamaged by fire forest area, where the main species of natural origin grows, as well as single trees of birch as a companion species. Figure 6.

A temporary sample plot of 0.25 ha was established at this site, where a complete enumeration of trees was made to determine the sanitary condition and taxation characteristics of trees. The plantations are of old-growth age, and there is a mixed-age undergrowth (Figure 5).

As this key area is covered with natural plantations with clearings, there is a gradual natural regeneration by self-seeding. The dying off of overgrown stands is also observed as a process of natural forest regeneration [12]. During the period of planned thinning on the places of skidder tracks and lowlands there is an accumulation of undergrowth.

The key site No. 4 is located in section 11 of quarter 9 of the Novonezhinskoye lesnichestvo of the Semiozero forestry institution (Figure 7). The area of the forest section is 0.2 hectares, according to the category of protection this forest area belongs to the field – and soil-protective forests, there are natural forest plantations, i.e. self-seeding at the site of the fire, which are 17 years old. The average height

of the plantations is 4 meters, and the average trunk diameter at a height of 1.3 meters is 8 centimeters. The main forest-forming species in the area is the common pine. The growing stands belong to the III bonitet. At this site, the minimum height of soot is 2.5 meters, and the maximum height of soot is 17.0

meters. The type of fire is defined as a top fire of medium intensity crops completely burned to the point of cessation of growth. The soil type is hog sand with a density index of 100 on the Wile Soil density meter dial, i.e. from 0-14 cm/kg<sup>2</sup>, which is favorable growing conditions.



**Figure 6** – Background (control) undamaged by fire forest plot

In this key participatory area a sample plot was also established on the area of 0.25 ha to determine the condition of trees. In the cultures all plantations belong to V category of sanitary condition. There are also birch plantations in the crops, which have started regeneration.

According to the data of the last forest inventory conducted in 2019, the completeness of the stands is 0.6, and the average wood stock is 21 m<sup>3</sup> per hectare, that is, on this allotment before the fire the wood stock was 12.6 m<sup>3</sup> [8].

A 0.2 ha sample plot was established at this site, where trees were counted to determine the sanitary condition and taxation characteristics of the trees.

In order to assess the self-restoring capacity of the forest, the forest area where a large forest fire occurred in 2004 was selected as a key site. At the time of the survey, natural plantations and forest crops were observed on the site of the former fire (Figure 8).

An area where natural regeneration occurred was selected. A temporary trial plot was also established to assess the condition of the forest plantations. In

terms of growth and development, as well as other taxation characteristics, the plantations correspond to their age, have good annual growth, the impact of pests and diseases is not observed. Trees belong to I category by sanitary condition.

There are single stands of birch trees older in age and aspen stands of the same age as the main species and younger. The above-mentioned associated species are strongly depressed and there is a displacement of them by stopping their growth. There are also intraspecific natural decay – single dry and depressed pine stands, which is normal in stands with high completeness.

For normal further growth and high-yielding stands, thinning is necessary, which in turn also reduces fire risk and the occurrence of wildfires. As growth progresses, high-floor stands are susceptible to pest and disease infestation. The natural regeneration of 2005 at the moment of the survey is growing evenly, the stands are healthy, crowns are closed, no further regeneration is observed, as mature stands hinder the growth of seedlings.



Figure 7 – Key area 4

Key site № 5 is located in sections 4 and 5 of quarter 7 of Novonezhinskoye lesnichestvo of Semiozernoye lesnichestvo of the Semiozernoye forestry institution.

In section 4 of quarter 7 there are natural plantations, the area of the section is 1.3 hectares, according to the category of protection this forest area belongs to the field – and soil protection forests, the age of which is 73 years. The average height of plantations is 18 meters, and the average trunk diameter at a height of 1.3 meters is 20

centimeters. The main forest-forming species in the area is the common pine. The growing stands belong to the III bonitet. Soil type is hog sand with density index 130 on the dial of Wile Soil density meter, i.e. from 0-14 cm/kg<sup>2</sup>, which is favorable conditions for growth.

According to the latest forest inventory, conducted in 2019, the completeness of the stands is 0.5, and the average wood stock is 170 m<sup>3</sup> per hectare, that is, in this section before the fire, the wood stock was 221 m<sup>3</sup> [8].



Figure 8 – Key site 4, top view

Since this plot is a forest edge, the fire intensity was lower than in the neighboring plot with forest crops. Also, the fullness of the plantation has a great influence.

In section 5 of quarter 7 there are artificial plantations, the area of the section is 1.2 hectares, according to the category of protection this forest area belongs to the field – and soil protection forests,

the age of which is 44 years. The average height of plantations is 14 meters, and the average trunk diameter at a height of 1.3 meters is 12 centimeters. The main forest-forming species in the area is the common pine. The growing stands belong to the II bonitet. According to the data of the last forest inventory, conducted in 2019, the completeness of plantations is 0.8, and the average wood stock of 188 m<sup>3</sup> per hectare, that is, in this section before the fire wood stock was 225.6 m<sup>3</sup> [8].

It is worth noting that on the sites where pine and a number of other coniferous species were burned, the first to naturally appear are seedlings or shoots of birch (Figure 9). In turn, these species during the next 20-30 years prepare the ground for mass growth of the main species. But they can also grow simultaneously with self-seeding of the main species. Due to their biological peculiarity – fast growth, deciduous species, in particular birch overtakes the main species in growth during the first vegetation period.



**Figure 9** – Key Site 5. Birch regeneration after the fire

In natural stands there are trees belonging to category IV that have preserved the upper part of the crown, and these trees may serve as seedlings for natural regeneration in the future. Seedlings of 15-30 days old are also observed here in separate clumps. On average 5-6 pieces per 1 m<sup>2</sup>.

In this subdivision of key plot № 5, a medium-intensity overhead fire occurred, and stands up to the top were completely affected by the fire with no possibility of continued growth.

In this key area in Section 5, the forest floor, which was storing seed stock, was deeply burned, which will have a negative impact on natural regeneration.

In this key plot in Section 5, the forest litter, which stored seed stock, is deeply burned, which will have a negative impact on natural regeneration.

The key plot № 6 background plot is located in subdivision 32 of quarter 7 of the Novonezhinskoye lesnichestvo of the Semiozernoye lesnichestvo of the Semiozernoye lesnichestvo.

The area of the forest section is 1.4 hectares, according to the category of protection this forest area belongs to the protective forest belts along railroads

and highways, there are natural forest plantations, the age of which is 93 years. The average height of the plantations is 20 meters, and the average trunk diameter at a height of 1.3 meters is 28 centimeters. The main forest-forming species in this area is the common pine. The growing stands belong to the III bonitet. Soil type is hog sand with density index 100 on the dial of Wile Soil density meter, i.e. from 0-14 cm/kg<sup>2</sup>, which is favorable conditions for growth.

According to the latest forest inventory conducted in 2019, the fullness of the stands is 0.6 and the average wood stock is 204 m<sup>3</sup> per hectare, i.e. the wood stock in this plot before the fire was 285.6 m<sup>3</sup>.

At this site, a trial area of 0.25 hectares was established, where a complete enumeration of trees was made to determine the sanitary condition and taxation characteristics of trees.

This key site was selected as a background site characterized by a typical pine forest growing near the highway and the settlement, and birch plantations are also found. The anthropogenic load on the site is high, as the site is located near the settlement and along the highway. In terms of age, the stands are

old-growth. Undergrowth is present in this plot, but with poor dynamics. Mature plantations do not allow growth of young trees, only in a small area, where there is an unshaded and warmed area with tree crowns, there are shrubs and young pine trees. Birch stands are declining due to displacement of the main species.

Key site No. 7 is located in section 27 of quarter 54 of Kalininsky lesnichestvo of Semiozero forestry institution. The area of the forest section is 5.6 hectares, according to the category of protection, this forest area belongs to the protective forest belts along railroads and highways, there are natural forest plantations, the age of which is 53 years. The average height of plantations is 16 meters, and the average trunk diameter at a height of 1.3 meters is

16 centimeters. The main forest-forming species in this area is the common pine. The growing stands belong to the II bonitet.

Soil type is hog sand with a density index of 100 on the dial of the Wile Soil density meter, i.e. from 0-14 cm/kg<sup>2</sup>, which is favorable conditions for growth.

According to the last forest inventory conducted in 2019, the completeness of the stands is 0.7 and the average wood stock is 204 m<sup>3</sup> per hectare, i.e. in this allotment before the fire the wood stock was 1142.4 m<sup>3</sup> [8].

In this plot, there was an upward fire of medium intensity, and the plantations up to the top were completely affected by the fire without the possibility of continued growth (Figure 10).



Figure 10 – Key Site 7.

At this site the minimum height of soot is 14.0 m, and the maximum height of soot is 18.0 m. According to the survey on sanitary condition of plantations belong to V category. During the field survey it is observed that after the fire the natural regeneration is weak, in general the undergrowth on the site and before the fire was insignificant, only single young trees. Weak regeneration is due to the high density of stands, where mature stands hinder the growth and development of undergrowth. Forest litter was completely burned in the fire, and soil seed reserves were destroyed. The process of natural regeneration is possible only after the development of the burned area, i.e. after removal of burned trees

from the area and soil damage during skidding and other logging operations. This increases the likelihood of self-seeding of seeds from nearby seed trees.

### Conclusion

Thus, we have surveyed 7 key areas, among them the most affected by the forest fire are key areas No. 5 and No. 7, where there was a top fire of medium intensity. It should be noted that in the key site No. 5 in section 5 of quarter 7 of Novonezhinskoye lesnichestvo there are middle-aged forest cultures (44 years), and in the key site No. 7 in section 27

of quarter 54 of Kalininskoye lesnichestvo there are middle-aged natural plantations (53 years). The similarity of the two plots is their high fullness (0.7 – 0.8), bonitet (II) and stock per 1 hectare (190 m<sup>3</sup>). The plantations in these plots burned completely without the possibility of continued growth and regeneration, the height of the soot is over 12 meters.

We estimate the average bonitet of all studied key sites as III and this is due to untimely harvesting, which resulted in a decrease in the annual growth of the plantation. Sanitary condition of plantations in key sites №1, №5, №7 is unsatisfactory in comparison with other sites. Soils of the investigated key sites are not compacted and favorable for growth. In key plot No.1 there was a compacted crust in the surface soil layer.

Uneven natural regeneration of common pine after the fire was observed. Predominantly friendly seed sprouting is associated with more moistened lowlands and loosened soil areas.

Factors hindering the natural regeneration of pine forests include deep burning of forest litter and soil cover, mechanical impact on soil and seedlings of machinery used for the development of burned areas, *Rhizina undulata* fungus, which affects the roots of coniferous trees.

Low intensity of natural regeneration is expected in key areas № 5, № 7, where forest litter was completely burned during a strong fire, soil seed stock was destroyed. In the same way, during the development of burned areas the already appeared sprouts will be destroyed under the wheels of machinery.

The main factor contributing to natural regeneration of burned forests is abundant precipitation both in spring and fall. The natural recovery process after fire is uneven. The prolonged drought, which in 2022 contributed to the rapid spread of the fire, has also hindered natural regeneration in the forest in recent years. In 2023, the summer was also dry, with prolonged rains only at the end of the summer, which favored the

germination of pine seedlings. Seed material that failed to sprout in spring began to sprout in the fall, mainly in lowlands where moisture lasts longer. Also during field inspection of the fire sites spring sprouts were found on the sites of winter felling, during which skidding of fallen trees took place, which in turn damaged the topsoil, contributing to the entry of seeds into favorable, relatively prepared for sprouting soils. For the pine forests of this region, moisture, or rather its high level, plays a key role.

Forests that have been damaged by fire urgently need to be developed and cleared to avoid the spread of secondary stem pests and diseases. But this increases the risk of death of young pine seedlings that have already appeared during mechanized works.

The observation series presented in the study are undoubtedly short and do not cover a succession cycle of 100 or more years. At the same time, they make it possible to identify certain regularities of post-pyrogenic forest dynamics to analyze the speed and direction of these processes, as well as to use them in practical activities.

The study of recovery dynamics processes makes it possible to determine the nature and speed of compensation by plant communities for the changes caused by the disturbance factor. The recovery time of a plant community after a disturbance (stabilization time or relaxation time) is its fundamental characteristic. In this connection, the study of recovery processes of boreal forests after external disturbances, as well as a comparative analysis of the features of organization of disturbed and undisturbed communities is an urgent modern problem. The results of the conducted research can be useful in solving the question of the necessity to carry out reforestation measures on the burned areas of Kostanay region.

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