Evaluation of natural regeneration of *Pinus sylvestris* L. on burnt areas in arid steppe climate conditions

Ol'ga Lyavdanskaya[1*], *Galiya* Bastayeva[1], *Andrey* Kubasov[1], *Aleksandr* Nesvat[1], and *Raislu* Suleymenova[1]

[1]FSBEI HE Orenburg State Agrarian University, 18, Chelyuskintsev street, Orenburg, 460014, Russia

Abstract. The article presents the results of assessing the success of natural forest restoration of Scots pine in areas affected by crown fires in the conditions of the sharply continental climate of the steppes. The amount of *Pinus sylvestris* L. undergrowth was calculated by height groups, and its reliability was assessed in accordance with size categories. The vector of restoration of natural vegetation on burnt areas in steppe conditions is considered, in the presence of a seed bank of Scots pine. The features of restoration of post-fire vegetation as the most important element of bioecological monitoring are studied. The number of species of accompanying steppe herbaceous species constituting the basis of the flora of the studied object is established. The ecological features and degrees of detection of formation of vegetation after fire, as well as indirect information on possible mechanisms underlying the dynamics of diversity associated with the characteristics of natural and climatic conditions, are revealed, practical recommendations are given to promote the restoration of *Pinus sylvestris* L. in areas affected by forest fires in the conditions of the arid climate of the steppes.

1 Introduction

The Orenburg region is crossed in various directions by multiple invisible natural boundaries, here are the southern and northern, eastern and western ranges of distribution of many species of flora, and the main feature is that it is through this territory that the border between the steppe and forest-steppe passes. The reasons for the diversity and contrast of the natural environment of the region are due not only to the uniqueness of its geographical location, but also to the peculiarities of the history of the formation of natural landscapes.

A sharply continental climate with a tendency to aridization is characteristic of the steppe natural zone, which is under the direct influence of the Central Asian and Kazakhstan deserts and semi-deserts, and the northern parts of the steppe zone are more susceptible to the influence of penetrating arctic ones. [1].

The Turgai flora, with typical coniferous-broadleaf forest vegetation, was formed mainly in the Neogene period of the Cenozoic era and occupied territorially the entire

* Corresponding author: Romashkaoa@rambler.ru

Southern Urals, East Asia, Siberia, the Aral Sea region and spread to the shores of the Atlantic Ocean. Woody plants, as representatives of the Turgai flora, for millions of years prevailed in vast areas where chestnuts, elms, oaks, beeches, hornbeams, maples, lindens, poplars, alders, birches, liquidambar, viburnum, actinidia and many other woody and shrubby plants grew.

The presented modern floristic composition of forest-steppe and steppe vegetation in the territory we studied was formed to a large extent much later, and is a consequence of human anthropogenic activity and is represented by transformed natural-territorial complexes.

In steppe landscapes, small groves and small areas of oak and mixed forests alternate with wide areas of meadow steppes, which are mainly used for agricultural purposes [2-3].

The variation of forest cover of the steppe and forest-steppe territory is determined in wide limits from 10 to 25% of their northern and western parts, while the forest cover of the southern steppe regions does not exceed 2%.

In the Soviet period of development of our country, characterized by mass development of virgin lands, most of the steppe and forest-steppe territory was plowed up, and is already an anthropogenically changed transformed agricultural landscape.

In connection with the current changes in modern development, the level of anthropogenic impact on forest landscapes of the steppe and forest-steppe zone is becoming more and more noticeable. Among the factors of human influence on the environment, forest fires should be highlighted.

Every year, fires destroy significant forest areas and, in this regard, the issue of forest restoration in vast areas passed by forest fires is acute. This is an urgent task of a global scale, requiring targeted efforts.

In forestry, especially in the steppe and forest-steppe, the restoration of lost forests plays a key role. This is an important national task, and its implementation, given its scale, makes a significant contribution to solving the global problem as a whole.

In order to minimize the consequences of natural phenomena that occur after forest fires, and for targeted forestry measures aimed at ensuring stable restoration of forests of various types, it is necessary to develop recommendations for forest restoration work. This approach will make it possible to quickly create forests with a high level of productivity.

Considering the climatic conditions of the steppes from the point of view of their impact on the growth, development and stability of plantings, it is necessary to note the following:

- Particularly dangerous are late frosts in the spring and sudden onset of cold weather in the fall. The former damage forest crops and young trees, the latter lead to damage to seedlings and shoots.
- Insufficient precipitation in late spring and early summer, when vegetation needs moisture most, has a negative impact on the normal development of young deciduous trees.
- Low relative humidity combined with dry weather in May-July, determine the period of maximum fire danger in the forest, which falls on these months.

Among tree species, *Pinus sylvestris* L. occupies a leading position in terms of distribution. Its adaptability to various environmental conditions, from arctic to subtropical latitudes, allows Scots pine to occupy a vast territory in Eurasia.

In this study, an attempt was made to more rigorously analyze the natural restoration of forests of *Pinus sylvestris* L. in areas affected by fires.

In our opinion, such an assessment should be mandatory for all areas affected by forest fires in order to prevent negative consequences such as swamping, erosive changes in the soil and the formation of wastelands. This will allow us to develop and implement measures that promote the development and environmental stabilization of the most valuable forest stands.

Forest restoration is one of the most urgent and difficult tasks, both from an environmental and economic point of view, inextricably linked with the methods and standards of logging and the existing practice of forest management.

The problem of forest restoration in steppe and forest-steppe areas, in arid climate conditions, affected by forest fires, is extremely relevant. In this regard, the increased attention of scientists to this topic seems completely justified and logical, including research at all stages of forest restoration.

Restoration of forest species in burned-out forest areas becomes possible mainly due to the fact that after a fire the upper tier of trees becomes thinner. In addition, complete or partial mineralization of the soil, which occurs directly during the fire, plays an important role.

Compared to other trees, *Pinus sylvestris* L. has a number of bioecological advantages: it has a significantly higher chance of preserving seeds during fires, and it is also characterized by faster growth and better adaptation of young shoots to frost and other unfavorable environmental factors of arid territories.

It is the fire that creates the necessary conditions for seed germination and rooting of young trees when the forest litter or turf of steppe herbaceous plants burns out.

The formation and features of the renewal of forest plantations in pyrogenic areas are determined by many conditions [4-5].

The most important of them are the original species composition of the forest stand damaged by fire and the intensity of its damage, as well as the physical and chemical characteristics of the soil and their transformation under the influence of fire.

No less significant are the features of the relief of the burnt area, the weather conditions that developed after the fire, the depth of the burn and the specifics of the restoration of the living ground cover on the burnt area.

A review of scientific papers demonstrates disagreements among researchers: the prevailing opinion is that fires stimulate the regeneration and development of pine stands, but a number of scientists point to the negative impact of fire on the natural restoration of forests.

It is possible to resolve these contradictions, reflected in the literary analysis of the restoration of pine forests after fires, only through long-term observations in vast burnt areas.

Spontaneous restoration of forest cover is a complex and changeable mechanism, the effectiveness of which depends on many variables, such as the type of forest, the structure of the stand, the biological properties of forest-forming species, etc.

However, the most important is not so much the course of natural renewal itself, but the emergence of seedlings and undergrowth of economically valuable species. It is they, in these specific growing conditions, that are able to guarantee maximum productivity of forest plantations in the long term, which is of the utmost importance in areas with low forest cover.

As a result of forest fires, a significant number of burnt areas have formed in the steppe region, in the areas of which the processes of steppe formation are proceeding much faster than the processes of forest restoration.

2 Materials and methods

The objects of the study are territorially located within the steppe zone, which, in our opinion, is objectively suitable for studying the restoration processes of *Pinus sylvestris* L., on forest lands affected by fires.

Analysis of literary sources on the subject of research shows that in the same natural and climatic conditions of the steppe and forest-steppe zones, the restoration of *Pinus*

sylvestris L. on burnt areas and the formation of stable phytocenoses with the predominant participation of Scots pine can occur according to different scenarios.

Forest restoration is a process that strongly depends on the geographic location, weather conditions and soil type, which gives it individual features. These features are associated with the time of fruiting of trees, the frequency of abundant seed harvests, favorable conditions for their germination, the emergence of seedlings and self-seeding plants, as well as the subsequent development of young forest plantations. Within one type of primary forest, various burnt areas are distinguished, which represent ecological and dynamic sequences of post-fire changes in forest biogeocenoses, reflecting their age.

To conduct a study devoted to the analysis of natural restoration of Scots pine and the study of the specifics of the formation, growth and development of its young generation, a characteristic site was selected that reflects the dynamics of recovery processes after a fire. This site, located in a typical steppe area, suffered from a fire years ago.

As a result of pyrogenic impact, the above-ground cover and forest stand with the predominant tree species of Scots pine were completely destroyed.

In order to study the processes of natural regeneration of *Pinus sylvestris* L. in the burnt area, we carried out a census of the undergrowth and assessed its vital state. 25 census sites were organized in the burnt area for conducting research. The census of natural regeneration of pine was carried out in census sites measuring 2 m x 2 m. Only viable undergrowth of Scots pine was subject to census and assessment of its vital state; by height, it was divided into: small - up to 0.5 m, medium - from 0.6 to 1.5 m, large - more than 1.5 m.

During field census work, the undergrowth of *Pinus sylvestris* L. was divided into three categories depending on its vital state, characteristics of growth energy and development: reliable, dubious and unreliable. A reliable specimen of *Pinus sylvestris* L. was considered to be one that showed minimal damage, with lush and rich needles, noticeable growth over the past year, proportional crown and viable apical bud. Unreliable undergrowth is a class of young trees, distinguished on the basis of their ability to adapt to abrupt changes in the environment. Unreliable was, first of all, undergrowth with damage of various origins, with sparse and pale colored needles, umbrella-shaped crown, drying out in the shade.

Doubtful undergrowth is characterized by a number of features that distinguish it from reliable and unreliable undergrowth, in which the main evaluation criteria included relatively unstable growth of the axial shoot, growth for each assessed year less than that of reliable undergrowth, the presence of two-topped trees, yellow needles and an unevenly developed crown. During the field studies, the emphasis was placed on studying the factors influencing the emergence and development of the young generation of *Pinus sylvestris* L., as well as on establishing the causes of slow growth and the death of this undergrowth.

To observe and analyze the dynamics of undergrowth development, 25 accounting plots measuring 2 m x 2 m were laid out on the trial plot. The location of the plots was relatively uniform and corresponded to the scheme shown in Figure 1.

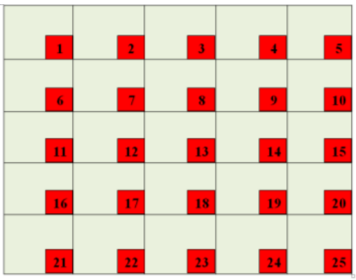

Fig. 1. Plan of systematic arrangement of survey plots in the area affected by forest fire.

As part of the research work, the following characteristics were recorded on the test plots: number of specimens, vertical structure, general condition and spatial distribution.

Forest restoration was assessed by analyzing individual undergrowth counts conducted on the selected sites.

The following indicators were determined:

- The number of undergrowth by age categories on the accounting sites.
- The proportion of viable undergrowth as a percentage of its total number.

The following formula was used to calculate the amount of undergrowth:

$$N = \frac{n*10000}{P} \quad (1)$$

Where N is the number of undergrowth per 1 ha, pcs.; n is the number of undergrowth of a given species in all survey plots, pcs.; P is the total area of survey plots, m^2; 10000 is the area of 1 ha in m^2. The following formula was used to determine the viability of undergrowth:

$$P = \frac{\mathrm{n}}{N*100} \quad (2)$$

According to the generally accepted formula P is viable undergrowth in %; n is the numerical indicators of viable undergrowth, pcs; N is the total number of undergrowth, pcs.

On plots measuring 4 m^2 within each 20 x 20 m square, the living ground cover was recorded and characterized.

For each identified species, the projective cover was estimated. This assessment was carried out using the Ramensky grid, a generally accepted tool in geobotanical surveys. Identification of plant species (their botanical affiliation) was carried out by generally accepted methods, using identifiers. The relative participation of various syntaxa was determined based on the total value of the constancy classes of species representing these syntaxa.

When characterizing vegetation, the abundance of species was estimated using the Drude scale with a simultaneous indication of their projective cover. The names of plant species are given according to the identifiers.

The analysis of the collected data obtained during practical research, field measurements and calculations was carried out using generally accepted statistical processing techniques using the functionality of the MS Excel spreadsheet editor, as well as specialized software “CurveExpert” and “Statistica”.

3 Results

The area affected by the forest fire is characterized by flat relief.

The main types of soil are ordinary chernozems, thick, slightly eroded, their formation occurred on homogeneous layers of clay, heavy medium loams of various origins in conditions of flat and slightly dissected relief. Territorially typical for the northern steppe zone.

Forest management materials and individual Scots pine trees preserved in the burnt area indicate that before the forest fire, 20-year-old pine young growth was located in this area.

As a result of the forest fire, almost all plantings in the area were damaged by high intensity, with the exception of the largest surviving Scots pine trees.

The perished plantings had a composition of -10C, and were assessed as II quality class.

The predominant type is a mixed-grass pine forest, characterized by moisture supply from rain and other atmospheric precipitation, a density of 60 to 70%, an average diameter of stands of about 16 cm, and a volume of wood reserves of about 120 cubic meters per hectare. The shrub layer is quite rare here, with a projective cover of only 5-10%. The vegetation cover develops extremely unevenly, denser in open areas and clearings, with a projective cover of 25 to 35%, while the moss cover is practically absent as a separate layer, only small areas of it can be found.

Mixed-grass pine forests are considered secondary forest types, as these forests are important for recreation and relaxation, as they create pleasant lighting, and the diversity of grasses makes them very attractive.

In the steppe and forest-steppe zones, these elements play a key role in environmental protection and maintaining the bioecological balance.

During the field taxation work on the territory affected by forest fires, the number of Scots pine undergrowth in the considered trial area reached 17,400 pcs./ha.

The size of the undergrowth, measured by height, fluctuated in the range from half a meter to two meters. The age of young trees did not exceed five years. Analysis of the annual increase in height shows a stable increase, which allows us to make a preliminary conclusion that the arid natural and climatic conditions of the steppe are quite favorable for the restoration of the Scots pine community on the burnt area.

The shrub layer during the formation of secondary successions on burnt-out areas is assessed as weakly developed, both in terms of species and numbers, and is represented by single bushes - common chiliga or tree caragana (*Caragana arborescens* Lam.).

The projective cover of the herbaceous above-ground cover is uneven and amounts to 45 - 100%, it is dominated by perennial mixed grasses: meadow fescue (*Festu capratensis Huds*.), awnless brome (*Bromus inermis Leyss*.), creeping wheatgrass (*Elytrigia repens* (L.) *Desv. ex Nevski*), narrow-leaved fireweed (*Chamaenerion angustifolium* (L.) *Scop*.).

On the southwestern side of the site there are adjacent artificial plantations of *Pinus sylvestris* L. aged 45 years.

The key and absolutely essential factor for the natural restoration of the Scots pine population in areas affected by a crown forest fire is undoubtedly the active production of seed by productive trees, that is, if the plantations located nearby have a sufficiently high reproductive potential, stimulating the active formation of undergrowth.

The size of the territories and the presence of seed sources have a noticeable impact on the process of natural restoration of vegetation in areas altered by natural fires.

When analyzing the undergrowth of *Pinus sylvestris* L. by its height, as one of the factors indicating the energy of plant growth, in the area covered by the fire, the following accounting metric data were obtained (Figure 2).

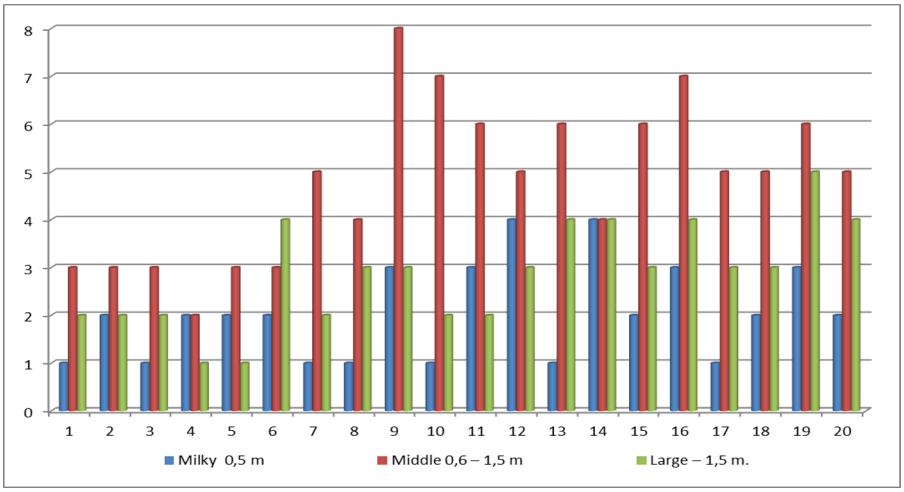

Fig. 2. The amount of *Pinus sylvestris* L. undergrowth by height groups in the test plot.

The survey plots for analyzing the growth and condition of the young growth of *Pinus sylvestris* L. were laid at a distance of 20, 40, 60, 80 m, respectively.

Having analyzed the amount of reliable young growth at the survey plots, it was found that at a distance of more than 60 m, the amount of young growth is 2 times less than at the forest wall.

In our opinion, this is due to the high degree of sodding of the soil cover by cereal perennials, which have a predominantly fibrous root system that contributes to the formation of a strong turf.

Accordingly, at the wall of the pine stand it is average, 60 m from the forest wall - strong. The number of young trees at a distance of 80 meters from the forest edge turned out to be ten times less than in the zone of 20-30 meters, which is probably due to a smaller amount of seed plaque. The entire undergrowth of *Pinus sylvestris* L. does not exceed 0.5 meters in height, which indicates that they are up to three years old.

Distribution of pine undergrowth by height groups showed that the undergrowth of *Pinus sylvestris* L. on burnt areas is in the stage of intensive growth, this, first of all, indicates its good condition, based on high growth energy and resistance over time to unfavorable natural and climatic factors of the steppe, with its arid climate and low amount of precipitation.

Research conducted on burnt areas allows us to conclude that the main obstacle to the renewal of *Pinus sylvestris* L. is the suppression of its young shoots by a powerful grass cover, which characterizes typical steppe vegetation.

Analysis of the conditions for self-renewal of forest plantations in the shade of a forest massif and in open areas (in this particular case, in an area affected by a forest fire) shows that in open areas the soil environment is characterized by greater volatility and instability.

Many scientific studies conducted both in Russia and abroad demonstrate that optimal conditions for the germination of Scots pine *Pinus sylvestris* L. seeds, both under the forest canopy and in open areas, are formed on bare mineral soil. At the same time, extreme conditions, such as a lack or excess of moisture, as well as unfavorable temperatures, lead to the fact that even in such areas the environment becomes unfavorable for seed germination and the further successful development of young plants.

4 Discussion

The relief of the entire study area is quite uniform and even, which determined the topological and typological homogeneity of the vegetation cover at the landscape level in the areas.

Observations of the burnt areas revealed the absence of grasses and young shoots of trees and shrubs during the first year after the fire. The probable cause of this is the change in soil characteristics due to the fire, in particular, its darkening, as well as changes in the chemical and physical composition. In addition, high air and soil temperatures, low humidity and intense lighting in the burnt areas can also hinder plant growth.

In the following 2 - 3 years, a sparse grass cover was observed in the area affected by the forest fire, consisting mainly of ruderal vegetation, such as *Melilotus officinalis* (L.) *Lam*., *Euphorbia virgata Waldst*. & *Kit*., *Artemisia absinthium* L., *Taraxacum officinale* (L.). At the initial stage of plant community development, a ruderal-cereal association emerged, consisting of weeds and cereals. These plants became part of the ground cover of the forest edge layer adjacent to the pine forest.

A significant number of *Pinus sylvestris* L. seedlings, allowing us to confidently note the initial process of forest restoration in the areas affected by forest fires, appeared after 3-5 years.

Further studies showed that as the burnt areas became overgrown with herbaceous vegetation, the emergence of *Pinus sylvestris* L. seedlings sharply decreased, and after 10 years, seedlings were no longer observed, even in isolated cases.

A study of the herbaceous ground cover showed that in the burnt areas, the number of herbaceous plant species increased in comparison with the forest area not affected by the fire and amounted to 26 versus 18 herbaceous plant species.

The discovered relationship is explained by the fact that forest litter, which interferes with seedlings and grass growth in the burnt areas, was largely destroyed by fire, and the soil was saturated with ash elements. These changes favor intensive spread and survival of herbaceous vegetation in the surveyed burnt areas.

Study of the condition of pine undergrowth in the area affected by the fire allowed us to obtain the following results (Table 1).

Table 1. The number of pine undergrowth according to reliability in the trial area.

Categories of undergrowth by height	Vitality status for pine, %			Total, %
	trustworthy	untrustworthy	dry	
small	86	14	-	100
medium	92	8	-	
large	97	3	-	

Using generally accepted methods, we calculated the number of *Pinus sylvestris* L. undergrowth per 1 ha, which was 17,400 pcs.

The percentage ratio of the vital state of the undergrowth shows fairly high results in terms of its reliability at the stage of the study, equal on average to 92% for the categories small, medium, large.

The analysis showed that the density of the undergrowth is 17,400 specimens/ha. In this population, small undergrowth is represented by 2,700 specimens/ha, medium - 9,600 specimens/ha, and large - 5,100 specimens/ha.

An assessment of the qualitative characteristics of pine undergrowth in burnt areas revealed the presence of 16,000 specimens/ha of reliable undergrowth and 1,400 specimens/ha of unreliable undergrowth. The share of reliable undergrowth dominates, amounting to 92%.

Pinus sylvestris L. is quite successfully regenerated on burnt-out areas, especially in places where the litter is destroyed by the powerful energy of a crown fire to the mineral horizons of the soil. In this case, in steppe conditions, the turf burns out completely and does not prevent the successful germination of Scots pine seeds and the shoots take root quite quickly, forming reliable undergrowth.

It can be assumed that the possibility and intensity of post-fire forest successions are influenced by a number of reasons and factors of the natural environment.

These include, first of all, the proximity of natural sources of forest species seeds (areas of natural forest plantations or artificial forest plantations), favorable soil conditions, solar activity cycles, etc.

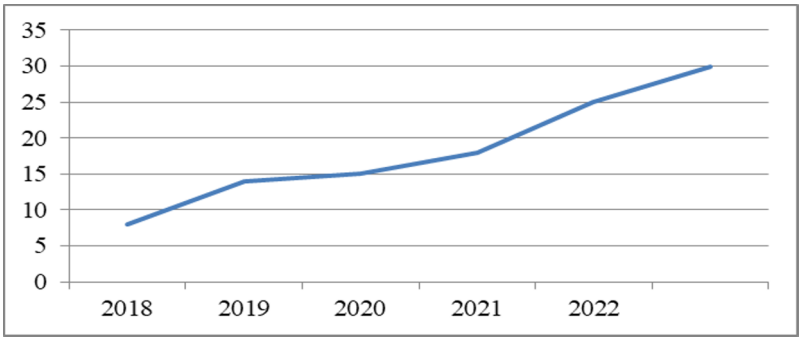

Fig. 3. Dynamics of linear growth of central shoots of Scots pine undergrowth on a burnt area, see.

As secondary successions form in areas affected by forest fires, the degree of sodding by steppe cereal vegetation increases, and conditions become impossible for the germination of *Pinus sylvestris* L. seeds.

In the burnt areas we studied, the amount of viable undergrowth is 92%. It has good growth in height and develops intensively (Figure 3).

Fig. 4. *Pinus sylvestris* L. undergrowth in the study area.

5 Conclusion

The forest growing conditions of the steppe are favorable for the growth of *Pinus sylvestris* L. and the formation of its plantations of high quality indicators.

The assessment of the restoration of *Pinus sylvestris* L. in the considered area of the typical steppe, with its sharply continental climate with a tendency to aridization, showed that the undergrowth develops quite actively, its number at the age of 5 years reaches an average of 17,400 pcs./ha.

The undergrowth of *Pinus sylvestris* L. is assessed as reliable, develops well, has active energy of growth in height.

The results of the studies showed the following, the implementation of SSF (clear sanitary felling) with subsequent measures to promote natural regeneration, if there are no viable pine plantations nearby, cannot be prescribed. Stimulating natural restoration of the forest after such felling is not advisable in the absence of a source of seeds in the form of healthy pine trees nearby.

Preservation of trees of damage categories 3-4, which survived the fire with minimal damage to the trunk and root system, as a source of seeds is not recommended. This is due to their inability to fully perform the key bioecological and reproductive function.

Around the second or third year, these plants begin to show signs of wilting, while their reproductive capacity decreases or disappears altogether.

In areas affected by forest fires and in the process of restoration of vegetation cover, the neutrality model is typical, which is a population process that includes a change in species that differ in the duration of the life cycle and adaptation strategies to environmental and phytocenotic conditions.

In areas of continuous burnt areas with nearby seed sources, it is advisable to stimulate natural forest regeneration. Such sources include forest walls (located at least on one side of the burnt area) or groups of trees of the parent forest stand (with a total crown density of at least 0.3...0.4) located along the edges of the burnt area.

The vital condition of the undergrowth according to the results of the conducted research is characterized as promising. Insufficient natural regeneration of *Pinus sylvestris* L. is observed in the part of the burnt area remote from the forest wall, where the effect of ruderal-cereal vegetation is maximally noted; here, soil turfing was observed due to the active spread of weeds and cereals.

The results of the research work demonstrate that such aspects as the level of illumination, the density of the grass cover, the varying density of tree crowns, as well as other parameters, determine the occurrence of undergrowth of different levels of development.

As recommendations for production, we propose to actively carry out forestry measures to promote natural regeneration in burnt areas by making narrow furrows or pricking the soil.

Currently, in the steppe zone there is no vector for reproduction and promotion of natural regeneration of plantings in areas affected by forest fires. Also, this knowledge is important for planning measures to preserve steppe biodiversity and rare species of flora and fauna, for the ecological restoration of damaged ecosystems and for stimulating the restoration of vegetation.

References

1. T.N. Vasilyeva, Z.N. Ryabinina, S.V. Lebedev, Phytosanitary status of disturbed ecosystems, IOP Conference Series: Earth and Environmental Science, Krasnoyarsk,

Krasnoyarsk Science and Technology City Hall of the Russian Union of Scientific and Engineering, IOP Publishing Ltd, Krasnoyarsk, **839**, 42042 (2021)

2. M.G. Turner, W.J. Calder, G.S. Cumming, T.P. Hughes, A. Jentsch, Sh.L. La Deau, T.M. Lenton, B.N. Shuman, M.R. Turetsky, Z. Ratajczak, J.W. Williams, A.P. Williams, St.R. Carpenter, Climate change, ecosystems and abrupt change: Science priorities, Philosophical Transactions of the Royal Society B: Biological Sciences, **1794**, 375 (2020)
3. L.M. Resler, Y. Shao, J.B. Campbell, Michaels A. Land cover and land use change in an emerging national park gateway region: implications for mountain sustainability, The Elgar companion to geography, transdisciplinarity and sustainability, Miami: Edward Elgar Publ., 270-292 (2020)
4. P. Potapov, M.C. Hansen, I. Kommareddy, A. Kommareddy, S. Turubanova, A. Pickens, B. Adusei, A. Tyukavina, Q. Ying, Landsat Analysis Ready Data for Global Land Cover and Land Cover Change Mapping, Remote Sensing, **12**, **3**, 426 (2020) DOI: 10.3390/rs12030426
5. M.G. Ozerova, O.Yu. Gavrilova, A.V. Sharopatova, The study of the environment ecological state from the position of its sustainable development, E3s web of conferences : VIII International Conference on Advanced Agritechnologies, Environmental Engineering and Sustainable Development (AGRITECH-VIII 2023), Krasnoyarsk, March 29–31, 2023, EDP Sciences: EDP Sciences, **390**, 01004 (2023)