FORESTRY IDEAS, 2022, vol. 28, No 2 (64): 334–351

Post-fire restoration of broad-leaved forests in the foothills of Dagestan

Zagirbeg M. Asadulaev and Parizat K. Omarova*

Federal State-Funded Institution of Science the Mountain Botanical Garden of the Dagestan Federal Scientific Centre of the Russian Academy of Sciences Makhachkala, Russia.
*E-mail: parizat.omarova.87@mail.ru

Received: 09 February 2022 / Accepted: 21 October 2022 / Available online: 07 November 2022

Abstract

The article presents the results of the analysis of woody vegetation renewal peculiarities after a crown fire, which broke out in 2010 in a beech-yew forest in Termenlik district (965 m a.s.l.) on the south-eastern slope of Gimrinskiy Ridge in the Foothill of East Caucasus in Dagestan. For the description of the changes, which occurred on the post-fire spot in 2019, eight sample plots with areas 100 m^2 each were arranged. A geobotanical description of the sample plots was conducted according to the generally accepted method, which included the definition of the microrelief, tree species composition, their distribution in the layers and biometric parameters. For each tree species, projective cover in percentage was revealed, as well as abundance, sequence of penetration and distribution, dynamics of the development of the above-ground part and the results of their competitive interaction were evaluated. Owing to the appearance of new species of seed origin with accelerated growth in the composition of the forest stand, such as *Populus tremula* L., *Salix caprea* L., *Acer campestre* L., *Fraxinus excelsior* L., a suggestion was made about the change of the succession trend and the formation of a newly reformed coenosis without participation of the basic dominant species of the primary forest, namely *Fagus orientalis* Lipsky, *Carpinus caucasica* L., *Taxus baccata* L., *Acer platanoides* L. A method of mechanical removal of the dominant species *Populus tremula* L. was offered, leading to the enhancement of the competitive advantages of pioneer species characteristics of this locality.

Key words: broad-leaved forest, competition, competitive advantages, crown fire, dominance, pioneer species, species richness.

Introduction

In Dagestan, due to the relative dryness of the climate, fires are a serious negative factor of destruction of established arboreal planting. Fires break out here in predominantly foothill woods in summer during prolonged drought and in intramountain and high-mountain forests in winter and early spring.

On the whole, forests occupy a relatively insignificant territory in Dagestan – 10.6 % (561,800 ha). According to the composition of the dominant species, they are represented by low-lying and mountain bottomland poplar and willow forests, foothill oak and beech-hornbeam forests, intramountain pine forests, high-mountain pine-birch and beech forests.

The above-mentioned plantations vary based on different susceptibility and resistance to fires and possess different demutation potential. It is widely accepted that coniferous forests are more susceptible to fires than broad-leaved ones (Proença et al. 2010).

At the same time, depending on ecological conditions of growth, conditions of origin, intensity of distribution, repetitiveness and duration of interfire intervals, the renewal of coenoses in the broad-leaved, as well as in coniferous forests, are subject to certain general patterns. Thus, out of the herbaceous plants the most widespread pioneer post-fire species, regardless of the type of forest, are *Chamaenerion angustifolium* (L.) Scop., *Impatiens noli-tangere* L., *Urtica dioica* L., *Calamagrostis langsdorffii* L. (Krasnoschyokov et al. 2010; Sabirov and Sabirova 2011, 2017; Sabirov 2019, Sabirov et al. 2019). Out of the arboreal species in place of burnt coniferous forests, due to its biological and ecological features, the first to appear is the pine, and the possibilities of its fixation in the burned-out forest grow despite the relative poverty of conditions of soil nutrition. Out of post-fire pioneer arboreal plants the most frequently mentioned species are *Populus tremula* L., *Salix caprea* L., *Quercus petraea* (Matt.) Liebl., *Acer campestre* L. (Komarova 1986, 1992; Komarova et al. 2007) and especially aspen species (Kuleshova et al. 1996, Kay 1997, Tereshkin and Tereshkina 2006, Komarova et al. 2007, Kalinin 2008, Ivanova and Golubtsova 2010, Khapugin et al. 2013, Krasnow and Stephens 2015).

This paper presents the results of studying the sequence of penetration and distribution of tree species in the post-fire area of a broad-leaved forest, the dynamics of development of their aerial parts, the competitive advantages of some species, and changes in the succession trend by mechanical removal of dominants.

The state of knowledge of the issue

The role of fires in the formation of forests has been summarized in many works (Melekhov 1981; Sannikov 1981; Komarova 1986; Furyaev 1988, 1996; Sabaeva 2005a). They deal with the conditions of their appearance, intensity and peculiarities of their distribution, repetitiveness linked to the ecological regimen of natural complexes, morphological structure and the character of post-fire coenoses, as well as the duration of interfire intervals.

It is universally recognized that fires have a strong impact on the condition of afforestation and are one of the main factors of their attenuation and death. The resistance of forests to fires is influenced by many factors: climate, structure of coenoses, trees size (Keyser et al. 2017). While comparing climatic and typological conditions in order to explain the patterns of renewal of forests after fire, even the local variety of geological layers turned out to be important (Torres et al. 2016).

Meanwhile, many researchers consider fire an important factor stimulating forest formation in nature. The resulting change of layers and the following post-fire successions are considered to be the most widespread form of forest dynamics on the territory of North Siberia (Rozanov 1999), in the south of Siberia (Buryak et al. 2007), in the basin of the Amur river (Sokolova and Verkhoturov 2019), in the Central Yakutia (Utkin 1965, Lytkina and Protopopova 2006, Nikolaev 2010), in Crimea. The forest is formed after the fire depending on its periodicity, ecotope conditions, intensity of combustion providing the so-called ‘pyroecological’ conditions (Druzhinin 2013).

Special significance during the assessment of vegetation in the burned-out forest is attributed to the initial number of newly settled species, which are responsible for the speed and direction of the succession process (Sabaeva and Nikitina 2004; Sabaeva 2005b, 2006; Kalinenko et al. 2006). In the very first years the number of species can reach ‘from 17 to 30‘ thousand examples per hectare and even 235 thousand examples per hectare (Dancheva et al. 2015). Later the increase in number of each species can vary depending on their biological peculiarities, provision with moisture and moesorelief. According to the universally accepted opinion, the absence of competition in the first years after fire leads to the spread of the species, mainly anemochores, and the bloom of their seeds is possible tens of kilometres away. In some cases burned-out forests are covered with grassy vegetation from main-rooted and rhizomatous species (Asadulaev and Omarova 2016), which preserve leader buds in the soil.

In the conditions of sufficient humidification of the soil after fires, the most frequent species to spread, out of the arboreal species, are the species of aspen and willow, which can lead to the change in the development of the stand of trees in the direction of enhancement of their role (Kuleshova et al. 1996, Tereshkin and Tereshkina 2006, Kalinin 2008, Khapugin et al. 2013). The role of aspen as pioneer species of the post-fire renewal of forests, contributing to the biodiversity of forest landscapes, is indicated in reference to many regions of the Holarctic (Kay 1997, Komarova et al. 2007, Ivanova and Golubtsova 2010, Krasnow and Stephens 2015). For example, in the western part of the USA, aspen, having the ecological amplitude, grows in wermuth steppes, in orohylile forests and sometimes reaches the tree line (Mitton and Grant 1996). It has been noted that, compared to coniferous forests, aspen stands provide enhanced afflux of water and resistance of ecosystems to fires (Shepperd et al. 2006). For this and other reasons many researchers consider aspen forests the most important type of post-fire deciduous forests (Long and Mock 2012). Aspen is widespread not only after fires, but also on the territories deserted after the extraction of the minerals, landslides, timber cutting and other breach of forest systems (Shepperd et al. 2006).

The question of longevity of the existing and newly emerged aspen forests is being discussed in the literature. The majority of the specialists hold the opinion that the longevity of the existing aspen forestry is achieved through clonal reproduction, and the capture of new violated territories occurs due to the multiple seedlings (Einspahr and Winton 1977, Turner et al. 2003, Landhäusser et al. 2010, Krasnow et al. 2012, Fairweather et al. 2014, Krasnow and Stephens 2015). The latter opinion about the spread of aspen trees on burned-out areas as a result of drifting of seeds from the outskirts has also been proven on the post-fire spot examined by us in the locality Termenik in the Foothill Dagestan (Asadulaev and Omarova 2016). As there are no big forests of this species here, there are only sporadic examples among beech and hornbeam forests. In some works on preservation of longevity of aspen forests, it is recommended to conduct rejuvenation of existing stands, removal of coniferous trees, controlled setting fire and protection from herbivores (Shepperd et al. 2001, Jones et al. 2005, Bates et al. 2006).

Among other post-fire pioneer arboreal species in the warmest habitats with periodically dry and poor soils, *Quercus mongolica* Fisch. ex Ledeb., *Acer mono* Maxim. ex Rupr., *Pinus koraiensis* Siebold & Zucc. (Southern Sikhote-Alin) have been cited (Komarova 1986, 1992; Komarova et al. 2007).

The most widespread post-fire pioneer species out of the herbaceous plants are *Chamaenerion angustifolium* (in rhododendron and clusterberry pine forests) (Krasnoschyokov et al. 2010), *Corydalis* (in pseudo-taiga larch forests of the Central Khangai) (Dorzhsuren and Krasnoschyokov 2007), *Impatiens noli-tangere* – in the areas with greater soil humidity, *Urtica dioica* – on rich and humid soils in oak forests of the Mordovia State Nature Reserve.

At the first stages of post-fire renewal in the course of the pyrogenic succession the number of species of herbaceous plants initially grows, while at the later stages it decreases. Only by the fourth year perennial plants slowly replace annual ruderal species (Sabirov and Sabirova 2011, 2017; Sabirov et al. 2019). On the spots with low fire intensity the richness of annual herbaceous plants is higher, while on the spots with high intensity there has been observed the opposite situation. The number of indicator species decreases as fire intensity grows. There has been detected a higher level of carbon, microbal biomass and nitrogen on spots without fire compared to post-fire spots (Heydari et al. 2016). The grass canopy is thought to fix the surface faster than trees and it protects it from erosion, which is especially important in mountain conditions.

The majority of researchers noted that in the first years after the ground fires conditions are formed, which are close to the optimal for the emergence, survival and growing of plantlets of trees owing to the removal of competition on the part of herbaceous-shrub layer, improvement of water and physical peculiarities of soils and enhancement of biological cycling of substances (Sannikov 1981, Maslakov 1984, Dylis 1985, Evdokimenko 2008). In other cases, a significant impact on the reconstruction of vegetation after fire is made by the so-called ‘nanny-plants’, i.e. secondary succession can be launched in the state of pioneer coenosis by means of increase in the frequency of emergence of seedlings of tall shrubs, aiphyllous and deciduous trees under the small shrubs (Siles et al. 2008).

The most extensive information in literature related to post-fire succession processes and the consecutive stages of changing of dominant species has been presented in reference to the Russian coniferous forests. It has been noted that their reconstruction varies in different regions and it depends on certain physiographic and geological-geomorphological conditions. The first issue to be addressed is the fact that the radical change of light conditions after the fires leads to disappearance of the majority of typically hylile photophygous species from the coenosis. Newly created ecological niches are immediately inhabited by heliophilous plants the most widespread of which from the herbaceous species is *Chamaenerion angustifolium*.

The first species, out of the arboreal ones, which appears on the burned-out spot during the burning of coniferous forests due to its biological and ecological peculiarities, is *Pinus koraiensis* but the possibilities of its settling for a long period are limited, except for the ‘extreme’ landscapes. Under the crown layers of the pine, as well as under the birch, which accompanies it, fir begins to grow, which slowly occupies the second layer of the forest stand and later penetrates the upper layer. It is impossible for the pine undergrowth as a heliophilous plant to grow here till the next fire passes. Such a regimen of existence of pine forests is called pyrogenic stability. In the majority of cases autochthonous coniferous forests are replaced after the fire by the derivative secondary parvifoliate (birch and aspen) or light coniferous forests (Sannikov and Sannikova 1985).

Besides, in reference to *Pinus koraiensis* there has been substantiated a hypothesis of 'impulse pyrogenic induction' of its renewal. An idea was proposed of the fire as 'information matrix' providing the continuity of horizontal structure of phytocoenoses. The modern ideas of the diverse role of cyclically repeating fires in the transformation of the main components of biogeocoenoses in the forests of light coniferous formation of the taiga zone of the northern hemisphere are considered to be proven (Sannikov 1981, Sannikov and Sannikova 1985). In the pine and fir forests (for example, on the territory of the Kola Peninsula) existing at different stages of post-fire successions there have been demonstrated similar common patterns of formation of age-related, size and vitality structure of coenopopulations. Such data are the evidence of existence of unified mechanisms in the core of which there lie laws of 'intrapopulation competitive interaction of the specimens and ecological and coenotic regulation of renewal processes' (Stavrova et al. 2016).

The most detailed study of the content, structure, formation and development of arboreal ecosystems after fires has been conducted by Sabirov (Sabirov and Sabirova 2011, 2017; Sabirov et al. 2019). On the island of Sakhalin in the light coniferous forests formed by *Larix cajanderi* Mayr, dark coniferous forests formed from *Picea ajanensis* Fisch. ex Carrière. and *Abies sachalinensis* (F. Schmidt) and in the dark coniferous forests with admixture of broad-leaved breeds *Phellodendron sachalinense* (F. Schmidt) Sarg., *Quercus mongolica* Fisch. ex Ledeb*, Kalopanax septemlobus* (Thunb.ex A. Murr.) Koidz., *Acer mono* ssp. *mayrii* (Schwer.) Kitam. Single plants of initial species appear in the second year after the fire. By the third year *Chamaenerion angustifolium*, *Copaifera langsdorffii* Desf., *Vaccinium vitis-idaea* L. actively settle. By the fifth year, *Carex van-heurckii* Müll. Arg., *Scorzonera radiata* Fisch. ex Ledeb., as well as *Artemisia arctica* Less., *Tilingia ajanensis* Regel & Tiling. begin to settle successfully. In the tenth year after fire the occurrence of *Copaifera langsdorffii* Desf., *Chamaenerion angustifolium* decreases significantly and the occurrence of *Carex van-heurckii* Müll. Arg. reaches 95–97 %. At the same time there appear larch, fir, aspen, Siberian dwarf pine (*Pinus pumila* (Pall.) Regel), *Betula middendorffii* Trautv. & C.A. Mey., *Duschekia maximowiczii* (Callier) Pouzar, *Spiraea betulifolia* Pall. In place of burned-out larch forests, sometimes develop pioneer species of mosses, lichens and the Kurile bamboo (*Sasa kurilensis* (Rupr.) Makino & Shibata), completely covering the soil surface, which poses a serious obstacle to the successful dissemination and growth of the indigenous arboreal coenoses.

On the whole, the duration of the renewal of the fir forest in the southern taiga is estimated to be 120–150 years. If we consider a multiple-aged spruce forest as the final phase of the succession, then 150 more years are required for its formation.

There is less information on the evaluation of post-fire successions in the broad-leaved forests in the literature. The sequence of renewal of such forests in the east of the USA and the south-east of Canada can be cited as an example (Krasnow et al. 2012, Krasnow and Stephens 2015). Here the dominant species of pioneer coenoses in the first year is *Digitaria*, in the second year it is *Rumex*. After the second year, there appear perennial herbs, among which woundwort (*Solidago*) prevails. By the 15–20-th year the bluegrass (*Andropogon*) and other graminoids prevail. By the 30–35-th year the poic stage can be followed by the bush stage where at first low bushes (*Viccinium, Gaylussacia*) dominate, then tall bushes do (*Quercus ilicifolia* Wangenh.). By the 50-th year the forest stand is completely restored. The first dominant species is the pitch pine (*Pinus rigida* Mill.), later the scarlet and white oaks (*Quercus coccinea* Muenchh., *Quercus alba* L.) appear. These species form young pine and oak forests with well-developed bush cover. Only by the 200-th year, if there are no recurring forests and other breach, an oak forest is formed with insignificant participation (or complete absence) of pine and bushes.

Materials and Methods

The research was carried out in a section of beech-yew forest burned down in 2010 in the Foothills of Dagestan, located at an altitude 965 m above sea level on a slope with north-eastern exposure (Fig. 1).

Study of the patterns of post-fire renewal of the forests in Dagestan has not been conducted before. We initiated this research in 2011–2013 in the area of

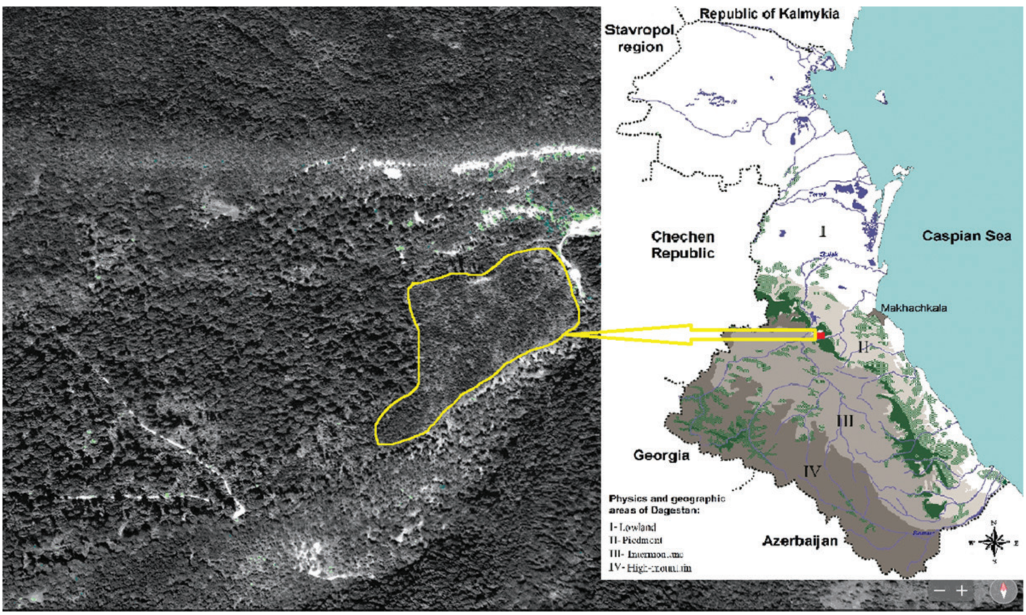

Fig. 1. The area of the burnt forest in the locality Termenlik on the map of East Dagestan.

Note: Caucasus (red dot) and a satellite picture on the Google map (yellow outline). On the map of Dagestan under number II a territory occupied by foothill broad-leaved forests is designated.

beech and yew forest burnt in a crown fire in the locality Termenlik in Foothill Dagestan (Asadulaev and Omarova 2016).

Six years later (in 2019) we continued to study the above-mentioned area. Tasks were set of revealing the sequence of penetration and distribution of arboreal species in the area, their species richness and abundance, dynamics of development of the above-ground part and evaluating the results of their interaction and competitive advantages. There were simultaneously arranged events aimed at changing the trajectory of post-fire renewal of the species composition of the forest using the method of mechanical removal of the dominant species (Krasnow and Stephens 2015), in our case it was *Populus tremula*.

According to the classification offered by Melekhov (1981), the post-fire forestland in the locality Termenlik in the Foothill Dagestan, where we conducted our study, has been assessed by us as the forestland with the forest stand destroyed in the crown fire (the year of fire being 2010).

For the description of further successive changes, which have occurred here since 2011, in 2019 we arranged eight sample areas (SA), 100 m^2 each (10×10 m). The geobotanical description of the SA was conducted following the generally accepted methods (Methods … 2002) and included the definition of the microrelief, revealing the tree species composition, their distribution in layers and biometric parameters of each species. For each tree species, a projective cover in percentage and the number of specimens were revealed. The development of arboreal plants was defined based on the height and diameter of the crown.

The assessment of renewal of arboreal vegetation after the crown fire was conducted in 2019 using the indices of species richness (alpha-diversity) and abundance. The first index was defined as a number of species per area unit, the second one is considered to be more substantial and denotes the number of specimens in each species (its functional weight) (Gasanov 2006). For the evaluation of the species richness Menhinick's index by equation (1) was calculated (Gasanov 2008).

$$D_{Mn} = \frac{S}{\sqrt{N}}, \qquad (1)$$

where: D_{Mn} is Menhinick's index; S is number of revealed species; N is total number of specimens.

The basis of the latter index consists of different combinations between the number of revealed species (S) and the total number of specimens of all species (N). The great value of the index, according to the calculations, corresponds to a greater diversity and is related to, first of all, the measure of achievement by the coenosis of ecological balance with the environmental conditions.

While comparing the numerical indices of the species abundance, a question of the main dominant species and the succession trend of development of the post-fire broad-leaved forest in the Foothill Dagestan arises. To our mind, one can get the answer to this question by comparing two factors, namely numerical superiority of the species at the initial stage and the growth rates (biometric factors) of the trees.

The first factor is based on the relative abundance of species and can be calculated using the Shannon's index (P_j), which is the ratio of the number of specimens of given species to their total number in the sample, i.e. $P_j = \frac{n}{N}$.

Mathematical treatment was conducted by methods accepted in biology using the programme Statistica for Windows 6.0.

Results and Discussion

Evaluation of post-fire renewal of arboreal vegetation

On the examined spot after a year after the fire (in 2011) sprouts were discovered of seeds, ratoons and an undergrowth of ten arboreal species (*Acer platanoides* L., *Populus tremula*, *Fagus orientalis* Lipsky, *Carpinus betulus* L. *Tilia cordata* Mill., *Rubus caucasicus* Focke, *Euonymus europaeus* L., *Euonymus latifolius* (L.) Mill., *Euonymus verrucosus* Scop., *Sambucus nigra* L.). In the unburned forest adjacent to the post-fire area, in addition to the above-mentioned species, there are also: *Fraxinus excelsior* L., *Populus tremula*, *Rubus caucasica* Focke, *Quercus petraea*, *Ligustrum vulgare* L., *Mespilus germanica* L., *Rhamnus cathartica* L., *Ulmus glabra* Huds., *Acer campestre*, *Cerasus avium* L., *Crataegus monogyna* Jacq., *Crataegus* sp., *Pyrus caucasica* Fed., *Prunus divaricata* Ledeb., *Quercus macranthera* Fisch. & C.A. Mey. ex Hohen., *Rosa* sp., *Rosa canina* L., *Rubus idaeus* L., *Sorbus aucuparia* L., *Salix caprea*, *Sambucus nigra*, *Swida australis* (C.A. Mey.) Pojark. ex Grossh., *Betula litwinowii* Doluch., *Cornus mas* L., *Lonicera caprifolium* L., *Malus orientalis* Uglitzk., *Tilia cordata*, *Rubus caucasicus*, *Taxus baccata* L., *Ulmus minor* Mill., *Viburnum lantana* L., *Pinus kochiana* Klotzsch ex K. Koch, *Robinia pseudoacacia* L.

The number of pioneer species (due to the abundance of soil nutrition resources, the absence of competitors) in the next two years increased to 23 species (Table1). At the same time, the values of the species richness index remained very low. In subsequent years (in our case, from 2013 to 2019), most of the species growing in the vicinity (some earlier, others later) penetrated into the post-fire territory, including *Acer platanoides* L. *Carpinus betulus, Fagus orientalis*.

At the same time the number of species per area unit has increased significantly (in 2011 there were 10 species, in 2019 – 23), and the index 'the total number of specimens of all species' has changed slightly, or even decreased because of the increase in the size of specimens.

Table 1. Participation of tree species in the post-fire restoration of broad-leaved forest (year of fire – 2010, year of accounting – 2019).

Species	The number of specimens on the spot (100 m²)								Species richness	Specimens density of species per 100 m²	Occurrence, %
	1	2	3	4	5	6	7	8			
Acer platanoides	46	45	35	27	28	34	44	34	293	36.6	100
Populus tremula	9	51	12	7	26	40	22	6	173	22.6	100
Carpinus caucasica	22	0	36	52	2	2	18	22	154	19.3	87.5
Fagus orientalis	4	0	24	28	1	2	3	2	64	8.0	87.5
Salix caprea	8	7	4	0	7	6	18	5	55	6.9	87.5
Fraxinus excelsior	0	0	1	4	0	0	4	0	9	1.1	37.5
Tilia cordata	0	2	0	2	2	0	0	0	6	0.8	37.5
Betula litwinowii	0	0	0	0	4	1	1	0	6	0.8	37.5
Quercus iberica	1	1	0	0	0	0	0	0	2	0.3	25.0
Ulmus glabra	0	0	0	0	0	0	0	1	1	0.1	12.5
Malus orientalis	0	0	0	0	0	0	1	0	1	0.1	12.5

Crataegus monogina	1	0	0	0	0	0	0	0	1	0.1	12.5
Rubus caucasicus	1	1	1	0	1	1	0	0	5	0.6	62.5
Euonymus europaeus	1	1	0	1	0	0	1	1	5	0.6	62.5
Euonymus verrucosus	0	1	1	1	0	0	0	1	4	0.5	50.0
Sambucus nigra	0	0	1	0	0	0	1	1	3	0.4	37.5
Rosa canina	0	0	1	1	0	0	1	0	3	0.4	37.5
Euonymus latifolius	0	1	1	0	0	0	0	0	2	0.3	25.0
Rhamnus cathartica	0	1	0	0	0	0	0	0	1	0.1	12.5
Cornus mas	1	0	0	0	0	0	0	0	1	0.1	12.5
Ligustrum vulgare	0	0	0	1	0	0	0	0	1	0.1	12.5
Mespilus germanica	0	0	0	0	0	0	1	0	1	0.1	12.5
Lonicera caprifolium	0	0	0	0	0	0	0	1	1	0.1	12.5
Specimen density	94	111	117	124	71	86	115	74	792	99	
Species density	10	10	11	10	8	7	12	10	9.8		
Menhinick's index D_{Mn}	1.03	0.95	1.01	0.90	0.95	0.75	1.12	1.16	0.82		
The Shannon index									1.757		
Pielou's evenness index									0.845		

Based on the results of calculations made on the spot, Menhinick's index for the estimation of which there were used factors *S* (the number of discovered taxa) and N (the total number of specimens) has changed from 0.75 (on the spot with 7 species and 86 specimens) up to 1.16 (on the spot with 10 species and 74 specimens), the maximum number of specimens being 124.

Of the total number of species (39) growing in the unburned part of the forest, 16 species have not yet been found in the post-fire area during the period of ten years.

The missing species are the habitual species for the lower layers of broadleaved forests of the Foothill Dagestan, namely *Cerasus avium*, *Crataegus* sp., *Pyrus caucasica*, *Prunus divaricata*, *Quercus macranthera*, *Rosa* sp., *Rubus idaeus*, *Sorbus aucuparia, Taxus baccata*, *Ulmus minor*, *Viburnum lantana*, except for *Pinus kochiana* and *Robinia pseudoacacia*, which are not characteristic of such forests in Dagestan. The last species is invasive and occurs on the lightened spots along the roads, and the pine is solitary here and occurs on pebble outcrops along the river downcuts.

In the next years, given the preservation of the species abundance on the same level (around 800 specimens per 800 m^2) and increase in the number of species up to 37 (without the last two species), Menhinick's index will acquire a value equal to 1.3. Such an increase is to be expected in the next 10 years. Simultaneously with size enlargement of the trees growing here there will enhance a competition which will contribute to the withdrawal of a significant number of specimens (with the preservation of the total number of species, the number of each species can significantly decrease). The index factor will increase accordingly. On the whole, based on Menhinick's index, the optimum factors of species richness for the sample areas had not been reached by the year of 2019 and this process will be enhanced intensively.

Additional information on the condition of arboreal vegetation on the postfire spot is provided by the factor of species density, which is the number of species per sample area unit. This parameter in the sample area fluctuates between 7 and 12 species per 100 m^2.

In the first and the following years in all sample areas without exception two species were discovered (occurrence): *Acer platanoides* and *Populus tremula*. The difference between these two dominant species lies in the fact that the first species prevails based on the number and biomass gain (crown height and diameter), which defines its competitive advantages. A little more rarely (87.5) occur *Salix caprea*, *Fagus orientalis*, *Carpinus betulus*, whose biomorphological parameters are also much lower than those of *Populus tremula*.

The species abundance and the species density in the ecological studies are used for the evaluation of the prevalence of the species and its functional weight in the coenosis. The notion of species domination is derived from the species abundance (Gasanov 2008). In our case the highest indices of domination have been observed in the following species: *Acer platanoides* (293), *Populus tremula* (173), *Carpinus betulus* (154), *Fagus orientalis* (64), *Salix caprea* (55), the functional weight of which is 93.3 %. The share of Norway maple alone is 40 %. Practical experience shows that Shannon's diversity index (P_j) lies in the interval between 1.5 and 3.5 and rarely exceeds 4.5. In our case P_j = 1.757. As the number of species in the coenosis grows, so do the factors of the index. That is why in order to obtain the characteristics independent from the number of species in the sample, one apply to the calculation of the Pielou's evenness index (the ratio of the observed diversity to the maximum one).

The evenness index is rather high here, which makes it 0.845. As this factor takes the value from 0 to 1, one can deduce that the analyzed sample includes the majority of the species of the studied arboreal coenosis, and the high value of evenness corresponds to the situation of equal abundance of all species.

Biometric indicators of the development of arboreal species

Crown height and diameter are the most important biomorphological indicators reflecting the development of trees and their competitive advantages in woodlands. A high positive correlation was revealed between these indicators in the trees that grew on the site after fire (N = 754, r = 0.899). This dependence gave us the basis for comparing the data obtained for different types of species and using them to interpret post-fire processes.

In addition, according to the results of a two-way analysis of variance, differences in biomorphological indicators between the trees of the same species growing on different sites werenot proven (Table 2). This indicates the representativeness of the trial site data, i.e. the size of the plots of 100 m^2 fully reflects the overall morphological diversity of the arboreal species present here. At the same time, differences in height and diameter between species are significant; the effect of species differences (h^2, %) in height reaches 57.2 %, which is slightly higher than in crown diameter – 49.3 %. Based on statistical indicators for SA and for species, a further comparative analysis of arboreal species was carried out by the height of their crowns.

Table 2. The results of analysis of variance by crown indicators species.

Factors	Statistical factors						
	Df Effect	MS Effect	Df Error	MS Error	*F*	*p*	h^2, %
Crown height							
Sample area	7	22.04	13.7	13.20	1.66	0.19	3.4
Species	12	68.56	746	1.07	63.84	0.0000	57.2
Crown diameter							
Sample area	7	11.22	14.6	12.98	0.86	0.55	0
Species	12	65.33	746	1.51	43.09	0.0000	49.3

Note: *F* – Fischer's criterion; Confidence level: *$p < 0.05$, ** – $p < 0.01$, *** $p < 0{,}001$; h^2 – force of influence of a factor.

The correlation of the group of trees by crown height, irrespective of their belonging to a certain species, is represented in Figure 2. There are only ten groups with sizes from 0.5 to 9 m. The proportion of 'taller' trees assigned to four groups from 5 to 9 m on all the sites is insignificant and amounts to a maximum of 5 %, except for the sample area No.6, where the proportion of trees of these groups is about 26 %. The presence of bigger trees in sample area No.6 can be possibly explained by the environmental conditions, as this sample area is characterized by a more inclined microrelief, which contributes to a slightly bigger accumulation of moisture and elements of mineral nutrition. The majority of trees (from the total number of trees) can be attributed to plants from 1 to 2 m. *Populus tremula* and *Salix caprea* are practically not represented in this group. The group of the smallest plants with height of 0.5 m (the minimal size) is sufficiently representative (in some sample areas their share is

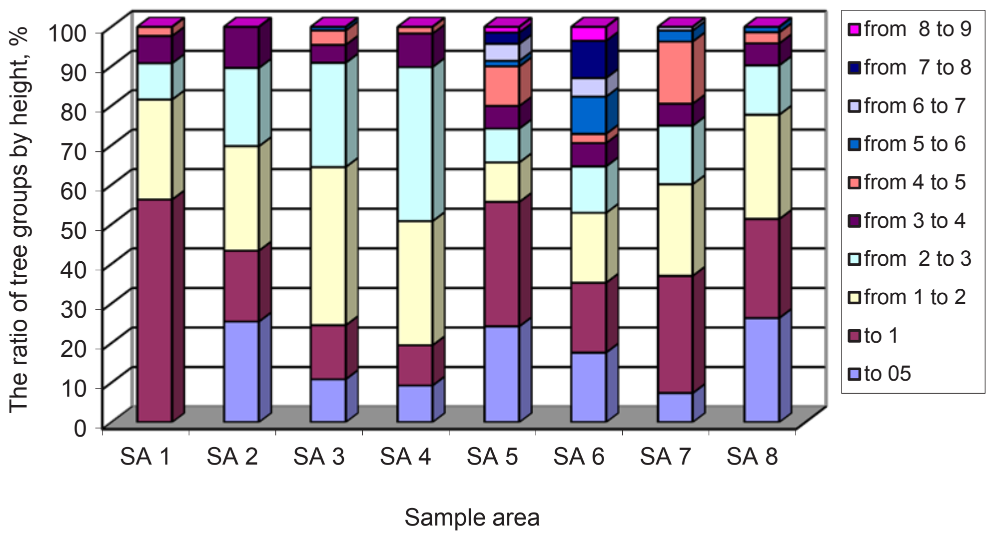

Fig. 2. Quantitative ratio of the trees according to their height in the sample area irrespective of their belonging to the species.

up to 20 %).

The significant number of plants of the latter group is associated with two factors. First of all, it points to the presence of species, which grow very slowly at the young age. For example, 5-year-old maple trees reach the height of 0.5 m, which is indicator of insignificant annual gain. Secondly, a high share of 0.5 m trees in the sample area points to the fact that every year seeds of plants of different species reach the sample area and the seeds of plants have been germinating for 10 years already (since 2011).

The picture that shows the distribution of specimens of different species by their sizes turned out to be more informative (Fig. 3). As shown in the figure, the whole of the left side (groups with specimens sized 4 m and above) is occupied by two species, namely *Populus tremula* and *Salix caprea*, while the right side is occupied by the 5 remaining species, i.e. *Fraxinus excelsior*, *Tilia cordata*, *Carpinus betulus*, *Fagus orientalis*, *Acer platanoides*. A special place is occupied by *Acer platanoides*, which has the highest share of plants with insignificant growth (293 specimens), (P_j = 0.369), where 95 % of specimens have the height less than 0.5 m.

The dispersion of the crown height index *CV* (%) in the sample area is significant in the species, while the lime-tree has the lowest one (5.6–31.7), which proves the identical growth rate of the specimens of this species. Populus trees have the highest dispersion (24.0–74.0) (Table 3). In this species in all sample areas there prevail middle-sized plants – up to 3 m (mode – 2.9), at the same time some specimens reach significant maximum sizes – up to 8.5 m. There also occur plants with the amount of growth less than 0.5 m. Hornbeam, ash-tree and lime-tree have approximately identical maximum size of the trees; the share of their height from the total height of all the trees (M_i, %) is approximately the same – 10–11 %. The maximum share from the total height of all trees is reserved for the aspen, which secures absolute competitive advantage for this species.

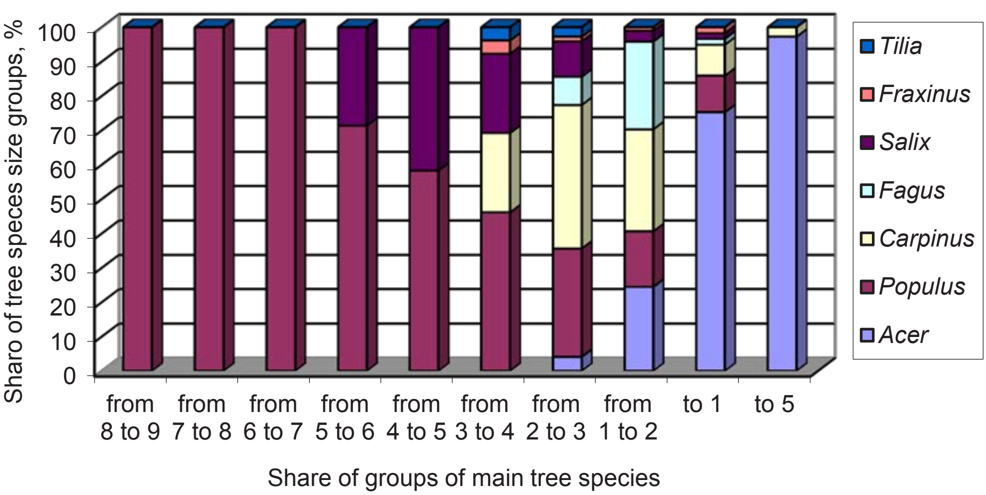

Fig. 3. The share of size groups of seven arboreal species on the post-fire forest spot.

Table 3. Statistical characteristics of the data based on the crown height of the main arboreal species in the post-fire forest area.

Indices	Tree species by genera							
	Populus	***Salix***	***Carpinus***	***Fraxinus***	***Tilia***	***Fagus***	***Acer***	***Betula***
CV, %	24.0–74.0	13.6–60.9	15.7–53.1	22.9–50.3	5.6–31.7	6.7–52.1	42.1–79.3	21.0
Mode, m	2.9	3.0	1.3	0.4	1.0	0.9	0.3	0.2
Maximum height, m	8.5	5.5	3.5	3.5	3.3	2.5	2.5	2.0
M_i, %	27	18	11	11	10	8	8	6

Note: *CV*, % is dispersion of the crown height index; M_i, % is the share of the index of the maximum height of each species in the total height index of the trees of all species.

At the same time, aspen trees have demonstrated significant drops in the amount of growth depending on the year; in 2014 it was reduced by two and a half compared to 2013 (up to 0.5 m), remaining on the same level for four more years (Fig. 4). The dynamics of growth of two other dominant species (in terms of number) of the second layer (maple and beech) has been homotypic and stable for years and it does not reflect the dependence on the ambient conditions.

The fluctuation of the annual amounts of growth shows that aspen is more sensitive to the conditions of moisture-providing of the soil and it, apparently, reflects the drops in the amount of precipitation in the same period (Table 4). According to the data provided by Buynaksk weather station in 2014, the amount of precipitation from April to July dropped by 136.7 mm (from 391 to 254.3 mm).

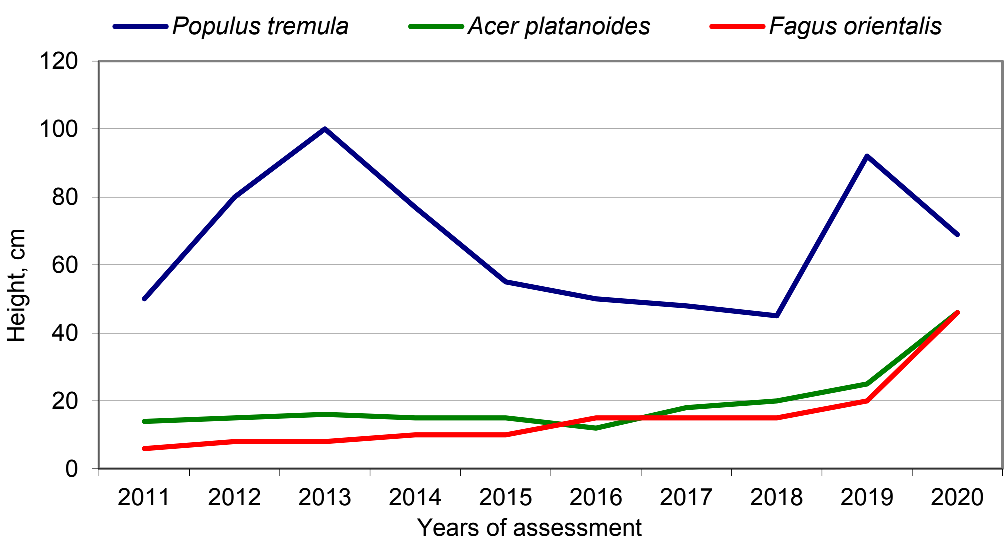

Fig. 4. Shoot growth dynamics of the dominant species in the sample area after the fire in the location Termenlik.

Table 4. The data reflecting the changes in the average late-spring and early-summer temperature and precipitation (from April to July) by year for the area Termenlik.

Indices	Years									
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Average temperature, °C	18.4	20.8	18.9	19.9	19.0	19.7	18.8	19.8	20.0	19.4
The sum of precipitation, mm	382	265	391	254	222	248	299	277	171	208

August 2014 was especially arid – only 7.8 mm. Radical fluctuations in the length of growth of the aspen can be explained by a greater dependence of the plants of this species on climatic conditions of the location, especially on the humidity of the soil (Tereshkin and Tereshkina 2006, Khapugin et al. 2013, Krasnow and Stephens 2015). In the following years the amount of precipitation was low, as well.

In two other species the lines representing the annual dynamics show gradual increase in the amount of growth. The growth curve (especially at the beginning of ontogeny) is considered to be species-specific and is less dependent on the ambient conditions than in the next years. The annual amounts of growth of the maple and beech in the first eight years after fire were insignificant, and in 2019 and 2020 the burgeon growth intensified – 22 and 24 cm, respectively. Such growth dynamics is associated with a more pronounced internal genetic control of the escape of these species (under relatively stable environmental conditions), and also means less dependence on precipitation fluctuations.

More intense annual burgeon growth naturally provides bigger total crown height of the trees. The average height of aspen trees in the sample area is 6.8 m, the maple – around 2.0 m, the beech – 1.5 m, which secures significant competitive advantages for the first species.

Conclusions

The study of the mechanisms and stages of the forest renewal after fire is an important task requiring long-term observations, the knowledge of natural pre-fire flora, methods of geobotanical studies, physiological peculiarities and the types of adaptive strategies of plants participating in the succession process. The obtained data, as a result of years of study, will hold importance for the explanation of natural processes of the renewal of broad-leaved forests in the Foothill Dagestan after fires, and at the same time they will be relevant for organizing events aimed at their artificial reconstruction.

By the 10-th year after fire the introduction of the main arboreal species from the part of the forest untouched by fire had practically finished (Pielou's evenness index = 0.845). Out of 39 potential species, 23 were discovered. The missing species are habitual for the lower layers of broad-leaved forests of the Foothill Dagestan, namely: *Cerasus avium*, *Crataegus* sp., *Pyrus caucasica*, *Prunus divaricata*, *Quercus macranthera*, *Rosa* sp., *Rubus idaeus*, *Sorbus aucuparia*, *Taxus baccata*, *Ulmus minor*, *Viburnum lantana, Pinus kochiana* and *Robinia pseudoacacia*, which are not dominant forest-making species and cannot define the trajectory of development of the demutation forest.

All sample areas without exception in

the first and the following years were dominated by two species – *Acer platanoides* (293 specimens per 800 m^2) and *Populus tremula* (173). High indices of abundance were registered in reference to the species *C. caucasica* (154), *Fagus orientalis* (64), *Salix caprea* (55). The difference between the indicated species lies in the fact that *Populus tremula* is only represented by a greater number, but also surpasses other species in terms of height and crown diameter (the average height of aspen trees is 6.8 m, maple – 2.0 m and beech – 1.5 m).

The numerical superiority and high growth rates (biometric factors) of the trees at the initial stage secure absolute competitive advantages for *Populus tremula* defining the trajectory of development of the post-fire demutation forest. Taking into account the resource and nature conservation value of the beech and yew forest for the locality Termenlik, the removal of the species dominating at the first stage of the forest renewal is important. This action is considered to lead to the enhancement of competitive advantages of other species with predictable consequences. In the studied post-fire coenosis the development will change in the direction of the beech and yew forest initial for this locality, and not the coenosis with the dominant aspen.

References

Asadulaev Z.M., Omarova P.K. 2016. Postpyrogenic dynamics of the vegetation of the beech and yew forest in the Foothill Dagestan. Russian Journal of Forest Science [Lesovedenie] 3: 209–215 (in Russian).

Bates J.D., Miller R.F., Davies K.W. 2006. Restoration of Quaking Aspen Woodlands Invaded by Western Juniper. Rangeland Ecology & Management 59: 88–97. doi: 10.2111/04-162R2.1

Buryak L.V., Kalenskaya O.P., Ponomaryov E.I., Sukhinin A.I. 2007. Fires and their consequences in pine forest strips of the south of Siberia. Conifers of the Boreal Area XXIV(4–5): 398–404 (in Russian).

Dancheva A.V., Zalesov S.V., Portyanko A.V. 2015. The evaluation of the success of the postfire reafforestation of pine forests in the Northern Kazakhstan. Kazakh Scientific Research Institute of Forestry and Agroforestry, Shchuchinsk, Kazakhstan; Ural State Forest Engineering University, Ekaterinburg, Issue 43: 77–79 (in Russian).

Dorzhsuren Ch., Krasnoschyokov Y.N. 2007. Postfire successions in the pseudotaiga larch forests of the Central Khangai in Mongolia. Conifers of the Boreal Area XXIV(4–5): 391–397 (in Russian).

Druzhinin F.N. 2013. Silvicultural evaluation of the renewal of the pine on the burned-out spots of Babaevsky district of Vologda Oblast. Druzhinin F.N., Shitova K.A. Dairy Farming Bulletin [Molochnokhozyaystvenny vestnik] 4(12): 13–19 (in Russian).

Dylis N.V. 1985. The carpet of leaves in the holocoenotic light. Russian Journal of Forest Science [Lesovedenie] 5: 3–8 (in Russian).

Einspahr D.W., Winton L.L. 1977. Genetics of quaking aspen. Research Paper WO-25. USDA Forest Service, Washington, D.C., USA 3: 20–23.

Evdokimenko M.D. 2008. Pyrogenic transformations of the pine forests in Transbaikal. Russian Journal of Forest Science [Lesovedenie] 4: 20–27 (in Russian).

Fairweather M.L., Rokala E.A., Mock K.E. 2014. Aspen Seedling Establishment and Growth after Wildfire in Central Arizona: An Instructive Case History. Forest Science 60(4): 703–712. https://doi.org/10.5849/forsci.13-048

Furyaev V.V. 1988. Analysis of the consequences of wildfires for the assessment of forest forming process. Russian Journal of Forest Science [Lesovedenie] 1: 59–66 (in Russian).

Furyaev V.V. 1996. The role of fires in the process of forest formation. Novosibirsk: Science [Nauka]. The Siberian department. 253 p. (in Russian).

Gasanov Sh.Sh. 2006. Structural ecology. Methodology and methods. Makhachkala. Science plus [Publishing house 'Nauka plyus']. 200 p. (in Russian).

Gasanov Sh.Sh. 2008. Ecometry: a textbook for university students. Makhachkala: Dagestan State University. 260 p. (in Russian).

Heydari M., Faramarzi M., Pothier D. 2016. Post-fire recovery of herbaceous species composition and diversity, and soil quality indicators one year after wildfire in a semi-arid oak woodland. Ecological Engineering 94: 688–697. https://doi.org/10.1016/j.ecoleng.2016.05.032

Ivanova N.A., Golubtsova O.S. 2010. Eco-geographical problems of nature management in oil and gas regions: theory, methods, practice. Proceedings of the 4th International theoretical and practical conference. Nizhnevartovsk: 131–134 (in Russian).

Jones B.E., Rickman T.H., Vazquez A., Sado Y., Tate K.W. 2005. Removal of encroaching conifers to regenerate degraded aspen stands in the Sierra Nevada. Restoration Ecology 13(2): 373–379. https://doi.org/10.1111/j.1526-100X.2005.00046.x

Kalinenko N.A., Nikitina N.N., Sabaeva N.I. 2006. Restoration of biodiversity of forest ecosystems in the Ishim region after fires. Ishim: Publishing House of Ishim Pedagogical Institute after P.P. Ershov. 156 p. (in Russian).

Kalinin K.K. 2008. Patterns of natural in the pine stands in big burned-out forests of the Middle. Bulletin of Mari State Technical University 3: 29–42 (in Russian).

Kay C.E. 1997. Is Aspen doomed? Journal of Forestry 95(5): 4–11. https://doi.org/10.1093/jof/95.5.4

Keyser T.L., McDaniel V.L., Klein R.N., Drees D.G., Burton J.A., Forder M.M. 2017. Short-term stem mortality of 10 deciduous broadleaved species following prescribed burning in upland forests of the Southern US. International Journal of Wildland Fire 27(1): 42–51. https://doi.org/10.1071/WF17058

Khapugin A.A., Vargot E.V., Shugaev N.I. 2013. Postfire change of vegetation in the broad-leaved forests on the example of an oak wood in the Mordovia State Nature Reserve named after P.G. Smidovich. Actual problems of environmental protection and rational nature management: 122–124 (in Russian).

Komarova T.A. 1986. Seminal renewal of plants in the fresh burned-out forests (forests of the South Sikhote-Alin). Vladivostok: The Far Eastern Branch of the Russian Academy of Sciences. 222 p. (in Russian).

Komarova T.A. 1992. Postfire successions in the forests of the South Sikhote-Alin. Vladivostok: The Far Eastern Branch of the Russian Academy of Sciences. 223 p. (in Russian).

Komarova T.A., Sibirina L.A., Yakovleva A.N. 2007. Formation and development of postfire forest stands in the forests of the South Sikhote-Alin. Russian Journal of Forest Science [Lesovedenie] 2: 12–21 (in Russian).

Krasnoschyokov Y.N., Evdokimenko M.D., Cherednikova Y.S., Boloneva M.V. 2010. Postfire functioning of the forest ecosystems in the Eastern Pribaykalsky District. Siberian Journal of Ecology 2: 221–230 (in Russian).

Krasnow K.D., Halford A.S., Stephens S.L. 2012. Aspen Restoration in the Eastern Sierra Nevada: Effectiveness of Prescribed Fire and Conifer Removal. Fire Ecology 8(3): 104–118. doi: 10.4996/fireecology.0803104

Krasnow K.D., Stephens S.L. 2015. Evolving paradigms of aspen ecology and management: impacts of stand condition and fire severity on vegetation dynamics. Ecosphere 6(1), 12. 16 p. http://dx.doi.org/10.1890/es14-00354.1

Kuleshova L.V., Krotkov V.N., Potapova N.A., Yevstigneev O.I., Kozlenko A.B., Rusanova O.M. 1996. Complex analysis of postfire successions in the forests of the 31. Kostomuksha Nature Reserve (Karelia). Bulletin of Moscow Society of Naturalists 101(4): 3–15 (in Russian).

Landhäusser S.M., Deshaies D., Lieffers V.J. 2010. Disturbance facilitates rapid range expansion of aspen into higher elevations of the Rocky Mountains under a warming climate. Journal of Biogeography 37: 68–76. https://doi.org/10.1111/j.1365-2699.2009.02182.x

Long J.N., Mock K. 2012. Changing perspectives on regeneration ecology and genetic diversity in western quaking aspen: implications for silviculture. Canadian Journal of Forest Research 42(12): 2011–2021. https://doi.org/10.1139/x2012-14

Lytkina L.P., Protopopova V.V. 2006. Wildfires as an ecological factor of the formation of forests in the Central Yakutia. Nauka i obrazovanie. Currently known as Arctic and Subarctic Natural Resources 2: 50–56 (in Russian).

Maslakov E.L. 1984. Formation of pine underwoods. Moscow, Forest Industry [Lesnaya Promishlennost]. 168 p.

Melekhov I.S. 1981. The influence of fires on the forest. Leningrad, Science [Nauka] 37. The Leningrad department. 150 p. (in Russian).

Methods of studying forest communities 2002. Saint Petersburg: Scientific Research Institute of Chemistry of Saint Petersburg State University. 240 p. (in Russian).

Mitton J.B., Grant M.C. 1996. Genetic Variation and the Natural History of Quaking Aspen. BioScience 46(1): 25–31. https://doi.org/10.2307/1312652

Nikolaev A.N. 2010. Dendrochronological study of postfire reaction of tree species in the Central Yakutia. Izvestiya of the Samara Scientific Centre of the Russian Academy of Sciences, volume 12, 1(3): 888–891 (in Russian).

Proença V., Pereira H.M., Vicente L. 2010. Resistance to wildfire and early regeneration in natural broadleaved forest and pine plantation. Acta Oecologica 36(6): 626–633. https://doi.org/10.1016/j.actao.2010.09.008

Rozanov S.I. 1999. Diversity indices in the assessment of the succession state of the ecosystems. Biology Bulletin Reviews [Uspekhi Sovremennoy Biologii] 119(4): 404–410 (in Russian).

Sabaeva N.I., Nikitina N.N. 2004. On the issue of studying the ecological role of plant excretions in phytocenoses in forest-steppe conditions. Ecology of southern Siberia and adjacent territories. Proceedings of International scientific school – conferences of students and young scientists. Abakan 2: 40–41 (in Russian).

Sabaeva N.I. 2005a. Dynamics of natural renewal of a pine in different types of forests in the conditions of the Ishim region. Collection of scientific works of postgraduate students, PhD and young scientists. Tara: 68–70 (in Russian).

Sabaeva N.I. 2005b. Ground fires as a factor of natural renewal of the Scotch pine (*Pinus sylvestris*). Ecology of Southern Siberia and adjacent territories. Proceedings of International scientific conference of students and young scientists. Abakan, vol. 2: 144–146 (in Russian).

Sabaeva N.I. 2006. The problem of the influence of ground fires on the processes of natural renewal of a pine. Collection of scientific works of postgraduate students, PhD and young scientists. Tara: 65–68 (in Russian).

Sabirov R.N. 2019. Certain aspects of post-fire restoration of larch forests in Northern Sakhalin. Intensification of use and restoration of the forests of Siberia and Far East. Proceedings of the All-Russia scientific conference dedicated to the 80th anniversary of formation of Far East Forestry Research Institute. Khabarovsk: 160–164 (in Russian).

Sabirov R.N., Melkiy V.A., Verkhoturov A.A. 2019. Assessment of violations of forest cover of the Northern Sakhalin by the fires with the use of aerospace methods. Aerospace and geoinformation technologies in silvics, forestry and ecology: reports of the 7th All-Russia conference. Moscow, Centre of Forest Ecology and Productivity of the Russian Academy of Sciences: 92–94 (in Russian).

Sabirov R.N., Sabirova N.D. 2011. Perennial dynamics of wildfires in Sakhalin. Geodynamical processes and natural disasters in the Far East region. Yuzhno-Sakhalinsk: Institute of Marine Geology and Geophysics of the Far Eastern Branch of the Russian Academy of Sciences: 179–180 (in

Russian).

Sabirov R.N., Sabirova N.D. 2017. Peculiarities of post-fire renewal of boreal forests in Sakhalin // Boreal forests: condition, dynamics, ecosystem services. Abstracts of the All-Russia scientific conference with international participation dedicated to the 60th anniversary of the Forest Research Institute of the Karelian Research Centre of the Russian Academy of Sciences. Petrozavodsk: 253–255 (in Russian).

Sannikov S.N. 1981. Wildfires as a factor of transformation of the structure, renewal and evolution of biogeocenosis. Ecology 6: 23–33 (in Russian).

Sannikov S.N., Sannikova N.S. 1985. Ecology of natural renewal of the Scotch pine under the forest canopy. Moscow, Science [Nauka]. 152 p. (in Russian).

Shepperd W.D., Bartos D.L., Mata S.A. 2001. Above- and below-ground effects of aspen clonal regeneration and succession to conifers. Canadian Journal of Forest Research 31: 739–745. https://doi.org/10.1139/cjfr-31-5-739

Shepperd W.D., Rogers P., Burton D., Bartos D.L. 2006, Ecology, biodiversity, management, and restoration of aspen in the Sierra Nevada. General Technical Report RMRS-GTR-178. USDA Forest Service, Rocky Mountain Research Station Fort Collins, Colorado, USA. 122 p. https://doi.org/10.2737/RMRS-GTR-178

Siles G., Rey P.J., Alcántara J.M., Ramírez J.M. 2008. Assessing the long-term contribution of nurse plants to restoration of Mediterranean forests through Markovian models. Journal of Applied Ecology 45: 1790–1798. https://www.jstor.org/stable/20144158

Sokolova G.V., Verkhoturov A.L. 2019. Dynamics of changeability of coniferous forests in the conditions of the Far Eastern climate, fires and felling. Intensification of use and restoration of the forests of Siberia and Far East. Proceedings of the All-Russia scientific conference dedicated to the 80th anniversary of the formation of Far East Forestry Research Institute. Khabarovsk, 10–11 October 2019: 170–174 (in Russian).

Stavrova N.I., Gorshkov V.V., Katyutin P.N. 2016. Formation of the structure of cenopopulations of forest forming species in the process of postfire restoration of northern taiga forests. Papers of Karelian Research Centre of the Russian Academy of Sciences 3: 10–28 (in Russian).

Sabaeva N.I.., Nikitina N.N. 2004. The problem of study of ecological role of vegetative emissions in phytocenoses in the conditions of forest-steppe. Ecology of Southern Siberia and adjacent territories. Proceedings of International scientific conference of students and young scientists. Abakan 2: 40–41 (in Russian).

Tereshkin I.S., Tereshkina L.V. 2006. Vegetation of the Mordovia State Nature Reserve. Consecutive rows of successions. Papers of the Mordovia State Nature Reserve 7: 186–287. (in Russian).

Torres J., Marques J., Alves P., Costa H., Honrado J. 2016. Local lithological drivers of post fire vegetation recovery and implications for fire prone regions. Ecological Research 32(1): 37–49. https://doi.org/10.1007/s11284-016-1415-2

Turner M.G., Romme W.H., Reed R.A., Tuskan G.A. 2003. Postfire aspen seedling recruitment across the Yellowstone (USA) landscape. Landscape Ecology 18: 127–140. https://doi.org/10.1023/A:1024462501689

Utkin A.I. 1965. Forests of Central Yakutia. Moscow: Publishing house of the Academy of Sciences of the Soviet Union. 206 p. (in Russian).