

PAPER • OPEN ACCESS

Post-fire restoration of tree species in various soil conditions after surface fires zone

To cite this article: D A Danilov *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **574** 012019

View the [article online](#) for updates and enhancements.

You may also like

- [Impact of fire on global land surface air temperature and energy budget for the 20th century due to changes within ecosystems](#)

Fang Li, David M Lawrence and Ben Bond-Lamberty

- [Vulnerability of California roadways to post-wildfire debris flows](#)

Rui Li and Mikhail V Chester

- [Modeling the effects of fire severity and climate warming on active layer thickness and soil carbon storage of black spruce forests across the landscape in interior Alaska](#)

H Genet, A D McGuire, K Barrett et al.



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Post-fire restoration of tree species in various soil conditions after surface fires zone

D A Danilov, I M Anisimova, N V Belyaeva and I A Kazi

Institute of forests and natural resources, *Saint-Petersburg State Forest Technical University named after S.M. Kirov*, 5 Institutsky lane, Saint-Petersburg 194021, Russian Federation

*Corresponding email: stown200@mail.ru

Abstract. The study of forest regeneration in stands exposed to fire has both fundamental and applied relevance. The objects of the study were the exposed to surface fires forest plots of various soil and hydrological conditions in the north-east of the Leningrad Region in the landscape of the Tikhvin ridge of the north-eastern part of the Valdai Hills. To study the natural renewal of tree species, circular plots of 10 m² were created along a transect traced over a diagonal of the area exposed to fire. Post-fire impact on soils with different particle size distribution causes the formation of stands with different shares of coniferous and broad-leaf species. After the exposure of tree communities to fire, regeneration processes can follow different directions in the formation of the future planting composition, and that depends on soil and hydrological conditions. Knowing the succession status of the post-fire plant community, further silvicultural measures can be planned for the management of stand composition.

1. Introduction

After Forest fires are characteristic of all countries of the world with significant forest resources, however, this problem is most relevant in countries with a continental climate and predominance of conifers in forests. There is a completely objective opinion that it is almost impossible to find a plot of forest in the taiga that has never been touched by a fire, and in many cases would not have been exposed to it repeatedly. Cyclically repeating fires are a powerful factor that influences forest soil formation [1-6]. Forest floor burning overlaps with alternating in time podzolic and sod processes, thus, regulating their intensity, duration and relative role in soil formation. Dramatically changing the chemical processes of the soil, and causing the substitution of mosses by grasses, the fire intensifies the sod cycle in the soil formation. As the moss cover re-grows and the pH of the soil solution changes, the sod cycle again gives way to the podzolic cycle [7-10]. During the first years, fire creates a favorable ecological niche for self-seeding of coniferous and broad-leaf species. The fire exposure results in the improvement of the soil substrate and the local conditions for seedlings emergence and development, it reduces the competition at all strata of a plant community and suppresses the activity of small animals that feed on seeds.

Many researchers who studied the origin and formation of vegetation in the taiga zone pointed out the role of forest fires in these processes [1, 6-9]. In particular, when characterizing the forests of Siberia, the European Russia, and North America, almost all researchers associate the variations in pine forests age with frequent fires and the subsequent emergence of new generations of forests on



fires sites and burns. The assessment of the existing concepts about the extent of the influence of fires on the processes of destruction, restoration, and formation of forests in the taiga zone requires a more detailed analysis of these questions.

To understand the causes of the existing diversity of forests and their current territorial distribution it is necessary to investigate the effect of fires on the reforestation process in a specific landscape, since under different soil and hydrological conditions also the natural regeneration of the forest will not be the same.

The study of forest regeneration in stands exposed to fire has both fundamental and applied relevance. These studies can guide on the changes that occur in the forest environment in various growth conditions under the influence of fire and what are the changes in the composition and abundance of underwood and grass cover in different types of forests. The examination of these objects allows determining the course of reforestation processes under different conditions, the relationships between grass cover, underwood, as well as emerging self-seed and undergrowth that survived the surface fires.

2. Methods and Materials

2.1. Objects of study

The existing relief of this landscape is formed by the accumulation of several stages of the last glaciation. It is characterized by a hilly moraine landscape with separate ridges of terminal moraines, with eskers and kames, in the southeastern part gradually changing into an outwash plain. Glacial moraine deposits are very diverse and range from heavy boulder loam to sand moraine. The Tikhvin Ridge lies on the Carboniferous period deposits. Relatively flattened areas are significantly swamped. Another characteristic feature of the landscape are numerous glaciolacustrine basins. The existing relief of the Tikhvin Ridge landscape is formed by the accumulation of several stages of the last glaciation [7, 11].

Forests cover 65% of this landscape region [12]. Most commonly these are spruce forests and spruce-small-leaved and aspen-birch forests that have grown after felling the spruce forests. East and southeast are dominated by lingonberry pine forests with heather and lichen; around the swamps these are boggy, long-moss and sphagnum stands.

Post-fire succession depends on various factors: geographical location, climate, landscape structure, area positioning, relief features, habitat types, biology of the species on the area, aspects of the forest type and succession phase, type and intensity of the fire, the size of the burned area, availability of seeding sources, seed quality, etc. [2, 4, 6, 7, 10]. The surveyed areas exposed to fire varied from 1 to 5 ha. The forest plots were exposed to fire during 2010-2013. After the fire exposure the damaged trees were removed. The soils in the analyzed areas have specific conditions from the point of view of the renewal processes of wood species. In all plots, the source of the renewal of the undergrowth was the maternal mixed coniferous stand of pine and spruce. Therefore, the contribution of this factor is probably equal on all the analyzed areas subjected to pyrogenic exposure.

To study the natural renewal of tree species, circular plots of 10 m² were created along a transect traced over a diagonal of the area exposed to fire. The undergrowth on these plots was registered using common forestry methods. On counting, the undergrowth was divided into three groups: small - up to 0.5 m high, medium - 0.5-1.5 m, and large - above 1.5 m [13, 14].

Soil samples of the plots were taken from organogenic mineral horizons. Humus content and soil solution reactions (pH) were estimated using the standard methods of soil science [15].

To analyze the relationships, we calculated the correlation ratio η of the dependent variable Y from the independent variable X , which can be obtained from the ratio of the intergroup variance to the total variance [15]. The theoretical correlation ratio is determined by the formula (table 1):

$$\eta = i - \frac{\sigma_{\text{res}}^2}{\sigma^2} = \frac{\delta^2}{\sigma^2} \quad (1)$$

where, δ^2 is the variance of the predicted values of the dependent variable, i.e. calculated by the regression equation; σ^2 is - variance of empirical (actual) values of the dependent variable; σ_{res}^2 - residual variance.

Table 1. Assessment of relationship based on theoretical correlation (Chaddock scale).

Value	Relationship	Value	Relationship
$\eta = 0$	None	$0.5 \leq \eta < 0.7$	Considerable
$0 < \eta < 0.2$	Very weak	$0.7 \leq \eta < 0.9$	Strong
$0.2 \leq \eta < 0.3$	Weak	$0.9 \leq \eta < 1$	Very strong
$0.3 \leq \eta < 0.5$	Moderate	$\eta = 1$	Functional

2.2. Experimental part

The registers of the renewal of tree species revealed differences in the number of tree species, their representation and size in areas with soils of different particle-size parameters (table 2-3). After fire exposure, the only wood species present in the plots with sandy dry soils are pioneer species of pine and birch. It should be noted that pine undergrowth is both more frequent and higher than other species.

Table 2. Post-fire restoration of undergrowth on sandy and sandy loam soils.

The number of undergrowth pieces per ha ^a					
Pine		Spruce		Birch	
H_{av}	number of pcs per ha	H_{av}	number of pcs per ha	H_{av}	number of pcs per ha
sandy dry soils					
0.5	4450	0.5	0	0.5	2550
0.51-1.5	5100	0.51-1.5	0	0.51-1.5	1725
>1.5	3800	>1.5	0	>1.5	600
0.5	2600	0.5	0	0.5	1800
0.51-1.5	450	0.51-1.5	0	0.51-1.5	250
> 1.5	125	> 1.5	0	> 1.5	100
sandy loam humid soil					
0.5	4200	0.5	50	0.5	1400
0.51-1.5	5525	0.51-1.5	75	0.51-1.5	6025
>1.5	3450	>1.5	125	>1.5	5425
0.5	3400	0.5	150	0.5	2400
0.51-1.5	3850	0.51-1.5	150	0.51-1.5	3325
> 1.5	2700	> 1.5	175	> 1.5	2325
0.5	4800	0.5	125	0.5	3700
0.51-1.5	5250	0.51-1.5	100	0.51-1.5	5525
>1.5	1525	>1.5	75	>1.5	1575
0.5	6100	0.5	350	0.5	5625
0.51-1.5	5725	0.51-1.5	150	0.51-1.5	3250
>1.5	7025	>1.5	375	>1.5	1225
sandy loam excessively humid soil					
0.5	550	0.5	0	0.5	25
0.51-1.5	0	0.51-1.5	0	0.51-1.5	250
>1.5	650	>1.5	0	>1.5	225

^a pine – *P. silvestris* L.; spruce *P. abies* Kr.; birch – *B. pendula* Rott.;

With an increase in the moistening, spruce was noted in the renewal process on sandy loam soils; the prevailing specimens are higher than 1.5 meters, which is apparently because smaller specimens

lose to birch undergrowth in the competition for photosynthetic resources and hydration. Comparing to birch undergrowth, pine undergrowth under these conditions is in much better position for its development, because it dominates the territory both quantitatively and by height. Also, on excessively moistened sandy loam soil, pine regeneration is dominant, both in the number of specimens and in height, whereas spruce undergrowth is not present.

Table 3. Post-fire restoration of undergrowth on sandy loam and peaty soils.

The number of undergrowth pieces per ha ^a					
Pine		Spruce		Birch	
H_{av}	number of pieces per ha	H_{av}	number of pieces per ha	H_{av}	number of pieces per ha
loamy soil					
0.5	300	0.5	900	0.5	200
0.51-1.5	400	0.51-1.5	1500	0.51-1.5	350
>1.5	150	>1.5	1500	>1.5	800
0.5	450	0.5	150	0.5	125
0.51-1.5	550	0.51-1.5	350	0.51-1.5	225
> 1.5	625	> 1.5	275	> 1.5	450
0.5	3150	0.5	225	0.5	1775
0.51-1.5	3575	0.51-1.5	350	0.51-1.5	2800
> 1.5	2500	> 1.5	450	> 1.5	2425
loamy gley soils					
0.5	175	0.5	75	0.5	200
0.51-1.5	125	0.51-1.5	4250	0.51-1.5	175
> 1.5	225	> 1.5	5250	> 1.5	300
peaty soils					
0.5	250	0.5		0.5	75
0.51-1.5	525	0.51-1.5	75	0.51-1.5	225
> 1.5	525	> 1.5	50	> 1.5	150
0.5	250	0.5	100	0.5	125
0.51-1.5	275	0.51-1.5	100	0.51-1.5	250
> 1.5	450	> 1.5	75	> 1.5	200

^a pine – *P. silvestris* L.; spruce *P. abies* Kr.; birch – *B. pendula* Rott.;

The renewal of spruce undergrowth on sandy and sandy loam soils is problematic from the point of view of its further development, since under these conditions spruce cannot create normally producing stands and will fall behind in growth and development. On coarser soils, post-fire restoration of wood often is characterized by spruce or birch dominance over pine undergrowth. Data from the surveyed plots show that there is a greater quantitative variability in renewed species. Apparently, an increasing humidity creates more favorable growth conditions for a young generation of spruce and birch. On excessively humid loamy gley soils, dominates tall and medium-size spruce undergrowth, since these are optimal growth conditions for spruce. On peaty soils of the drained swamp massif after fire exposure, pine undergrowth prevails again, whereas spruce renewal is insignificant. The share of renewed birch undergrowth constitutes up to one third of the total number of renewed species.

3. Results and Discussion

To determine the post-fire soil conditions for the renewal of species, we analyzed samples taken from the root layer of soil at 0–10 cm and determined the content of organic matter (humus, %) and the pH level in the studied areas. The obtained data were used to build graphs of the relationship between the number of undergrowth by species and humus content or pH level, as well as to calculate the correlation η for these variables (figure 1). For pine, the obtained estimates based on the theoretical

correlation ratio by the Chaddock scale show a strong correlation with the humus content in the root layer of the soil, $\eta = 0.733$, and a moderate correlation with the pH, $\eta = 0.435$. For spruce, the correlation was moderate, $\eta = 0.374$ for humus content, and $\eta = 0.371$ for pH. For birch, the correlation with a humus content was considerable, $\eta = 0.540$, with pH of the root horizon of the soil its value was $\eta = 0.435$.

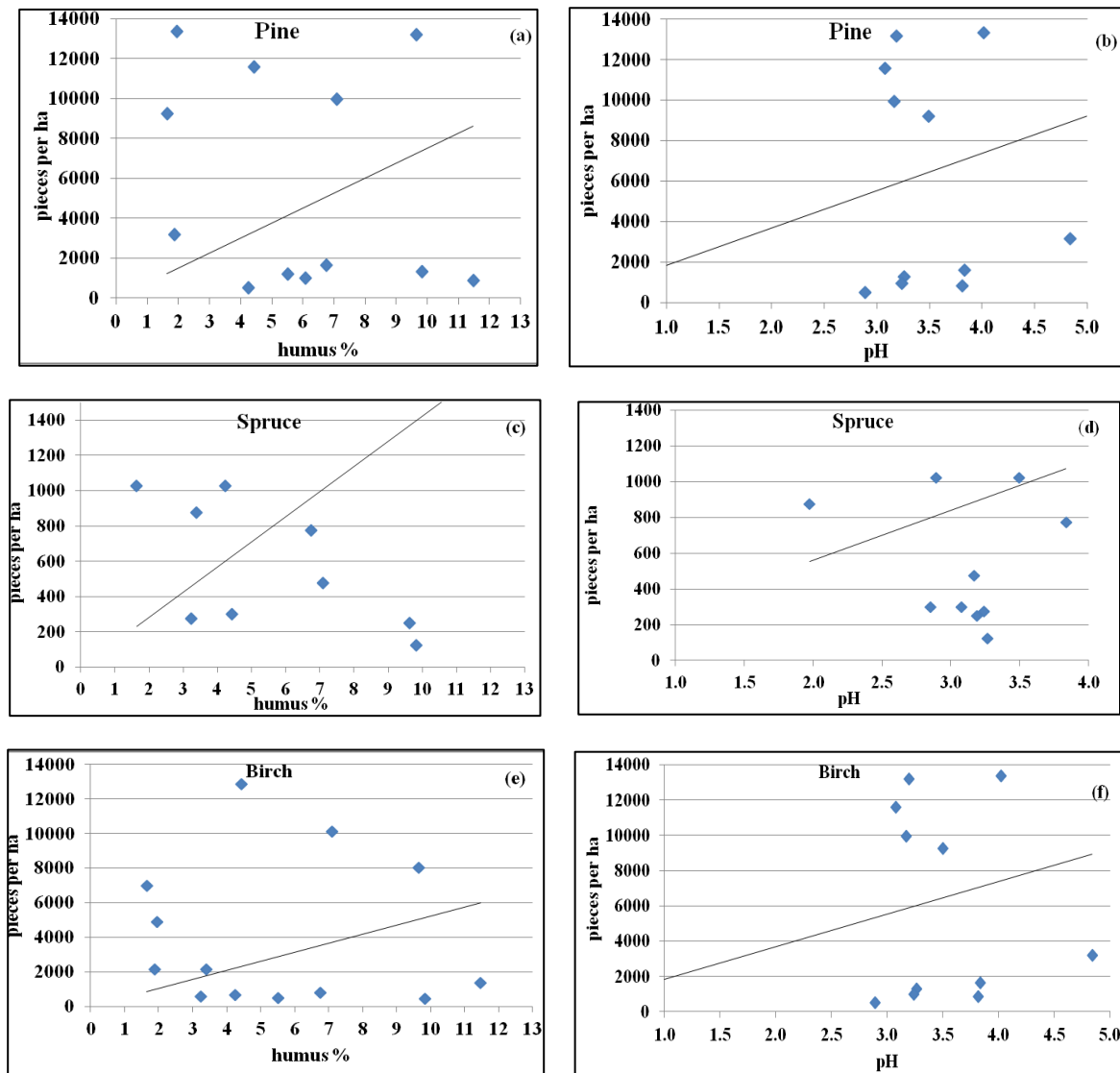


Figure 1. The influence of the humus content and pH in the root layer of the soil (0-10 cm) on the quantity of undergrowth.

To study further the influence of soil factors on the post-fire restoration of tree species, we analyzed the relationship of the restoration with the particle size distribution of the soil. The results show that pine undergrowth has the strongest relationship between its renewal and soil and hydrological conditions, demonstrating a very strong correlation with $\eta = 0.916$. It can be noted that after fire exposure, on finer soils pine and birch undergrowth is found in the largest quantity. For birch undergrowth, this correlation is strong, $\eta = 0.794$, therefore, it can be concluded that the number of undergrowth directly depends on the particle size distribution of the soil. With soil becoming coarser and more humid, the quantity of renewed spruce undergrowth increases. Based on the calculated

theoretical correlation coefficient, $\eta = 0.510$, the correlation of spruce renewal with soil composition indices can be qualified as considerable (figure 2).

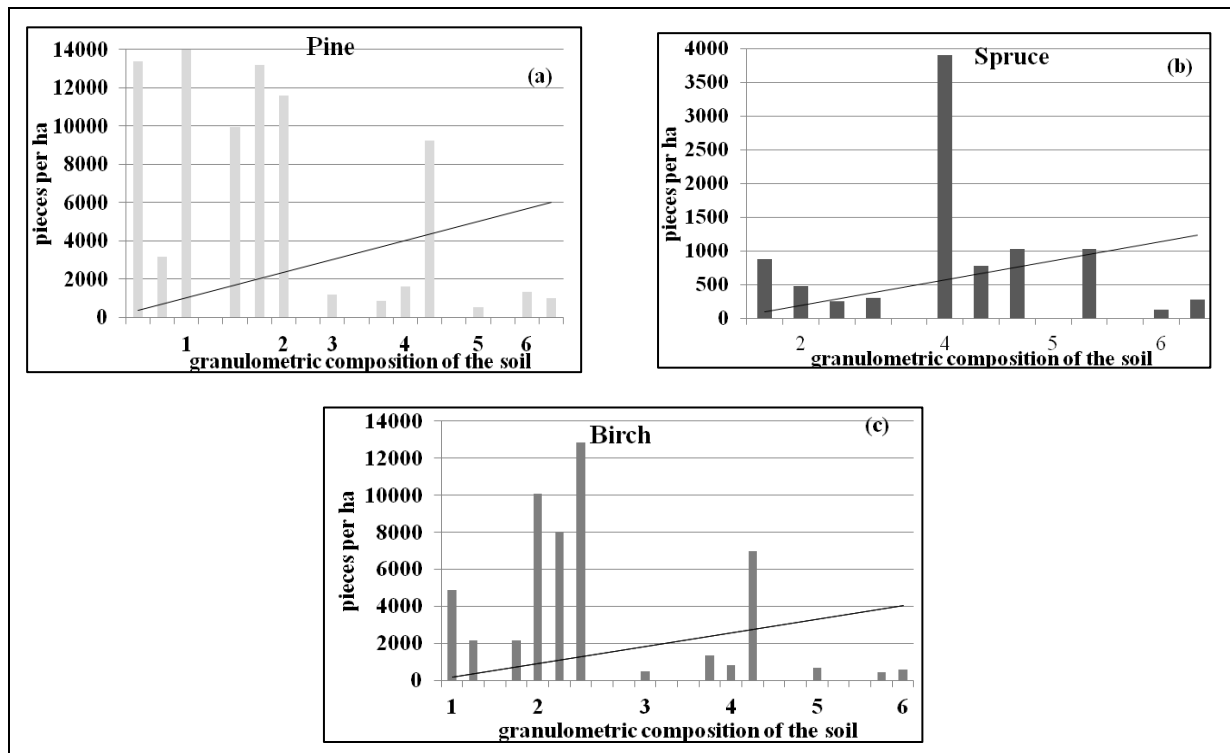


Figure 2. Influence of the particle size distribution of the soil on the quantity of undergrowth, where, 1- Sandy soil; 2- Sandy loam humid soil; 3- Sandy loam excessively humid soil; 4- Loamy soil; 5 - Loamy gley soils; 6- Peaty soils.

Considering the obtained results, it can be argued that at the initial stage of restoration of coniferous plant communities on sandy soils, the renewal process follows the classical pattern of a pine stand formation with the presence or admixture of birch. As the humidity of sandy loam soils changes, not only birch and pine undergrowth renews, but also spruce undergrowth, however, having only a small share among the total number of restored trees. More fertile loamy soils after exposure to fire create optimal conditions for growth and development of all species. Here, the key factor in the restoration of forest cenosis is, apparently, the presence of a sufficient amount of seeds in the maternal stand in the post-fire restoration period of the plant community. This is what, *ceteris paribus*, causes the predominance of spruce or pine in a forming stand. After fire exposure, loamy soils with a temporary excessive level of humidity create optimal conditions for the development of spruce stands. On peaty soils of the drained swamp after fire exposure, pine undergrowth mixed with birch renews successfully, while spruce undergrowth presence is insignificant.

Based on the performed study, the predictive succession pattern of post-fire restoration in the landscape of the Tikhvin Ridge, depending on soil and hydrological conditions, can be drawn as follows:

Sandy soil — *pine-birch forest stand or pine with the participation of birch forest stand.*

Sandy loam humid soil and Sandy loam excessively humid soil — *pine-birch forest stand mixed with spruce forest stand or pine-birch forest stand.*

Loamy soil — *pine-birch with the participation of spruce stand; pine-birch with an admixture of spruce or spruce-pine with the participation of birch.*

Loamy gley soils — *spruce with birch and pine forest stand*

Peaty soils — *pine with the participation of birch forest stand.*

Further development of these post-fire stands can occur without anthropogenic influence, and in this case, with a high degree of probability the proportion of birch in the stand will increase. With systematic treatment, it is possible to form a mixed pine and spruce plantation that meets the growing conditions or a stand with the presence of birch.

4. Conclusion

– Post-fire impact on soils with different particle size distribution causes the formation of stands with different shares of coniferous and broad-leaf species.

– In areas exposed to surface fires, the correlation between the quantity of pine undergrowth and such parameters as humus content and the pH of the soil solution is higher than the correlation of these parameters with the quantity of young generation of spruce.

– The amount of renewed birch also closely correlates with the content of organic matter and soil pH parameters, but to a lesser extent than pine undergrowth.

– After the exposure of tree communities to fire, regeneration processes can follow different directions in the formation of the future planting composition, and that depends on soil and hydrological conditions.

– Knowing the succession status of the post-fire plant community, further silvicultural measures can be planned for the management of stand composition.

References

- [1] Artsybashev E S 2014 Influence of fires on forest biogeocenoses. [in Russian – Vliyanie pojarov na lesnie biogeocenozi] *Biosphere* **11** (3) pp 53–59
- [2] Gusev D, Danilov D and Beliaeva N 2018 Analysis of the characteristic of the undergrowth after ground fire in the Leningrad region. [in Russian – Analiz sostoyaniya podrosta sosni posle nizovih pojarov v Leningradskoi oblasti] *Forestry log.* **8**(2) pp 46-54
- [3] Gusev D and Danilov D 2017 Comparative analysis of post-pyrogenic pine regeneration in the Luga and Putilov landscapes of the Leningrad region.[in Russian – Sravnitel'nyi analiz postpirogeennogo vozobnovleniya sosni v Lujskom i Putilovskom landshaftah Leningradskoi oblasti]*Moscow Economic Journal* **5** pp 41–48
- [4] Gromtsev A 2002 Natural disturbance dynamics in the boreal forests of European Russia *Silva Fenn.* **36**(1) pp 41-55
- [5] Gromtsev A N 2000 *Landscape ecology of taiga forests: theory and practice*. [in Russian – Landshaftnaya ekologiya taejnih lesov- teoreticheskie i prikladnie aspekty] (Petrozavodsk : Car. scientific center of RAS) p 142
- [6] Tsvetkov P A 2013 Influence of fires on the initial stage of forest formation in the Middle Taiga Pines of Siberia. *Coniferous boreal zone*, XXXI, **1** (2). pp 15-21
- [7] Fedorchuk V N, Neshatayev V Yu and Kuznetsova M L 2005 Forest ecosystems of the North-Western regions of Russia: Typology, dynamics, forest management features factors [in Russian – Lesnye ekosistemy severo-zapadnyh rajonov Rossii: Tipologiya, dinamika, hozyajstvennye osobennosti] (St-Petersburg) p 382
- [8] Rolstad J, Blanck Y L and Storaunet K O 2017. Fire history in a western Fennoscandian boreal forest as influenced by human land use and climate. *Ecol. Monogr.* **87**. pp 219–245
- [9] Ryzhkovaa N, Pintod G, Kryshena, A, Bergeronb Y, Olse C and Drobysheva I 2020 Multi-century reconstruction suggests complex interactions of climate and human controls of forest fire activity in a Karelian boreal landscape, North-West Russia *Forest Ecology and Management* **459** pp 117-770
- [10] Usenya V V Gordei N V and Teglenkov E A 2016 Evaluation of postpyrogenic formation of natural plantings in pine phytocenoses. [in Russian – Ocenka postpirogeennogo formirovaniya estestvennih nasajdenii v sosnovih fitocenoza] *Proceedings of BSTU*, **1**, pp 79-83
- [11] Isachenko A G 1994 Landscape zoning and landscape typology of Leningrad Oblast.General

- principles of forest management and landscape-typological strategy. [in Russian – Landshaftnoe raionirovanie i tipologiya landshaftov Leningradskoi oblasti. Obschie principi strategii lesopolzovaniya i lesoviraschivaniya na landshaftno_tipologicheskoi osnove] (Saint-Petersburg: Forestry Research Institute) pp 11-25
- [12] Forest Plan of Leningrad Region (2018)//www.lenobl.ru. – 27. 12. 2018
- [13] Gryazkin A V 1997 Patent No. 2084129, Russian Federation, IPC C 6 A 01 G 23/00. A method of accounting regrowth [in Russian – Sposob ucheta podrosta] No. 94022328/13; Declared 10.06.94; Published on July 20, 1997, Bulletin No. 20.
- [14] Andreeva E N *et al* 2002 *Methods for studying forest communities* [in Russian – Metodi izucheniya lesnih soobshchestv] (Saint-Petersburg: Research institute of chemistry of Saint Petersburg state University) p 240
- [15] Bankin M P, Bankina T A and Korobeynikova L P 2005 *Physical and chemical methods in Agrochemistry and soil biology*. [in Russian – Fizicheskie i himicheskie metody v agrohimii i biologii pochv.] (St. Petersburg: Publishing house of St. Petersburg state University) p 177
- [16] Gardener M 2017 *Statistics for Ecologists Using R and Excel*. Pelagic Publishing. p 406