Post-pyrogenic tree species regeneration under the Tikhvin Ridge landscape conditions, North-West Russia

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Abstract. The effect of ground fires on the success of later regeneration of tree species in the landscape locations of gentle hilly ridges of terminal moraines and ozovo-cam complexes of the North-Eastern part of the Leningrad Region was assessed. The study of the juvenile generation of tree species was carried out by a reconnaissance survey of forest areas traversed by wildfires on the transects of the tracks. The quantitative and heights of the re-growing tree species were taken into account. The method of correlation analysis was used to determine the degree of influence of external factors - soil conditions, the area of the plot passed by the fire on forest regeneration processes. The dependence between soil factors and categories of size of spruce and pine undergrowth in stands with a predominance of coniferous and deciduous species was determined. The size of the area covered by pyrogenic effects, depending on the granulometric composition of soils, has a significant impact on the regeneration of coniferous and deciduous species. Depending on the proportion of participation of pine and spruce and deciduous species, we can prognosticate the further development and formation of stands by species composition and prescribe forest management measures.

1. Introduction

The effect of fires on forest communities in the boreal zone is both destructive and positive [1, 2]. Researches on the pyrogenic effect on forest and subsequent restoration of tree species are carried out in many countries, where forest fires occur, both in the temperate zone and in the regions with an arid climate [3-5]. Some studies have explored post-pyrogenic succession in various regions [5-10]. As a result, there has been a different nature of restoration processes for different tree species depending on the relief, the dimension of areas affected by fire, their characterization of soil, and hydrology [4-6, 9, 10]. Depending on the landscape conditions, tree stands of various species composition are restored. They are often different from the initial plantations [6, 8, 9, 11, 12]. Study of the progress of regeneration processes at the landscape level makes it possible to schedule forestry measures for the formation of highly productive tree stands, depending on the soil and hydrological conditions of the sites, affected by pyrogenic processes of different intensity.

2. Methods and Materials

Ten–twelve-year-old post-pyrogenic plantations have been examined. They are forming after ground fires in landscape positions of gentle ranges of hills of terminal moraines and esker and kame complexes under the Tikhvin Ridge landscape conditions of the Boksitogorsky District, Leningrad Region, Russia, on clay-loam and peaty soils of different moisture regimes [2, 13]. This landscape is part of the Valdai Hills, the main zone of the marginal glacial formations of the last glaciation within
the Leningrad Region. These Hills are the largest orographic part of the entire North-West of the Russian Plain, being the watershed between the Baltic and the Caspian Sea Basins. This territory is the heaviest hilly relief strip, including marginal formations of several stages of the last glaciation retreat. The Tikhvin Ridge is a hilly upland in the South-East of the Leningrad Region with altitudes up to 280 m. Tikhvin Ridge is a result of accumulation of several stages of the last glaciation. The zone of the marginal glacial formations is characterized by the rugged hilly and lake landscape. There are well-represented moraine hills and ridges, kames, eskers, fluvioglacial deltas of glacial streams, and zvonetzes (elevated plateaux, composed of limnoglacial clays). The largest areas feature hilly-moraine topography. The diameters of the hills vary from 300-500 m to 1 km, and their relative height ranges from 15 to 50 m; their shape is round or elongated, the gradient of slopes is 10-25°. In the eastern part of the strip of the marginal glacial formations, the hilly-moraine relief is often significantly smoothed due to the influence of limnoglacial basins. The dominant heights are up to 200 m. The heights above are formed by zvonets groups. Eskers are differently oriented and are 10-15 km in length.

Evaluation of the possible success of the subsequent tree species regeneration with a predominance of spruce and deciduous species was carried out by exploratory accounting of forest areas affected by ground fires on transects of computation lines. The accounting of the vegetation and soil factors was maintained on the sites of 10m² each. They were laid along a straight line at 3 m from each other. This method makes it possible to research better the factors that determine the growth of woody plants on the given territory [14, 15]. During inventory, 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. The granulometric texture of soils was determined by organoleptic methods. To analyze the relationships, we calculated the correlation ratio \( \eta \) 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 (1):

\[
\eta = \sqrt{1 - \frac{\sigma^2_{res}}{\sigma^2}} = \frac{\delta^2}{\sigma^2}
\]

where: \( \delta^2 \) is the variance of the predicted values of the dependent variable, i.e. calculated by the regression equation; \( \sigma^2 \) is - variance of empirical (actual) values of the dependent variable; \( \sigma^2_{res} \) is - residual variance. The relationship between the indicators was assessed on the basis of theoretical correlation using the Chaddock scale [15, 16].

3. Results and Discussion

Forest sites, affected by ground fires on loamy-sandy, clay-loam, and peaty soils of various moisture regimes, have areas of 1-3.3 hectares damaged by fire. The categorization of the size of coniferous and deciduous trees undergrowth was analyzed for the areas, affected by ground fire. To determine the degree of success of forestry processes, all regenerated undergrowth was enumerated and divided into the categories of different sizes under forestry regulations and rules [13].

The economically valuable species regeneration success should be assessed from the point of view of forestry and the subsequent carding of young stands. It can be observed that high quantitative representation of spruce undergrowth belongs to the medium and large category in post-pyrogenic young stands with the dominance in numbers of spruce undergrowth on clay-loam fresh soils (figure 1). The pine undergrowth is also presented by medium and large categories. It should be noted that there is a significant quantity of pine and spruce small undergrowth. However, there is more spruce small undergrowth. In general, the quantitative representation of both species is sufficient for the formation of spruce-pine stands in the future. It is only necessary to adjust the number of deciduous species (figure 1). On peaty soils in plantations with spruce undergrowth predominantly, large specimens prevail; there is also medium undergrowth with a total number of over 2000 pcs. per ha, including small undergrowth. The pine undergrowth is presented by 450 pcs. per ha on average with large and medium categories predominantly. In post-pyrogenic young stands with spruce
predominantly, there are 350-700 pcs. per ha of birch undergrowth, and the natural predominance of aspen is from 150 to 350 pcs. per ha (figure 1).

![Figure 1](image1.png)

**Figure 1.** Distribution by size category of tree species regeneration in stands dominated by spruce on Loamy soils (a), Loamy gley soils (b), Peaty soils (c).

The comparative analysis made on two soil phases with good and excessive moisture regimes shows that the largest share of deciduous species is presented on wet sandy-loam soils, on average, more than 2000 specimens of birch and about 2000 specimens of aspen. The share of coniferous species (pine and spruce) is about 1200 pcs. per ha (figure 2). The quantitative representation of coniferous undergrowth is much higher on more fertile peaty soils and is about 1500 pine trees and about 1000 spruce trees. The share of birch is over 1500 pcs. per ha and aspen is about 1000 pcs. per ha (figure 2).

![Figure 2](image2.png)

**Figure 2.** Distribution by size categories of tree species regeneration in stands dominated by deciduous species on sandy Loam soils (a) and on Peat soils (b).
It should be noted that there is a large representation of pine undergrowth on both soil phases with large and medium trees predominantly. The spruce undergrowth has a lower number and approximately the same number of trees in all size categories. Medium and large specimens of deciduous species predominate. The insufficient number of coniferous undergrowth, 1200 pcs. per ha and about 4000 pcs. per ha of birch and aspen specimens, is optimal for the formation of coniferous-deciduous plantations on sandy loam and clay-loam soils with an equal proportion of species. At this age stage, completely removing the aspen regeneration in waterlogged soils will lead to a sufficient number of pine and spruce trees. It is enough to remove deciduous species for the subsequent formation of a relatively pure coniferous stands.

The obtained results indicate that after the pyrogenic effect, heterogeneities in the soil complex lead to a different number of species under conditions similar in granulometric texture. In plantations with spruce undergrowth predominantly, the correlation between the representation of its number and the granulometric texture of the soil is significant (R=0.42), and inverse and linear. As the granulometric texture becomes heavier, the number of spruce undergrowth increases. For the pine undergrowth, with the regeneration in post-pyrogenic sites with spruce young stands predominantly, the correlation between its quantitative representation and the granulometric texture is not linear and is well described by a second-order polynomial. An actual functional correlation (R=0.99) can be observed between the granulometric texture and the number of pine undergrowth. However, it should be noted that the highest representation of the pine undergrowth, as well as the spruce undergrowth, was recorded on fresh clay-loam soils. After the pyrogenic effect, the most favorable environment for the regeneration of spruce undergrowth developed in areas with more waterlogged soils (figure 3).

**Figure 3.** Influence of the particle size distribution of the soil on the quantity of regeneration spruce, pine, birch and aspen in stands dominated by spruce, where, 4 - Loamy soil; 5 - Loamy gley soils; 6 - Peaty soils.
For the deciduous species, the number of birch and aspen trees is also in non-linear dependence on the granulometric texture of soils. For birch, there is a more complex but high correlation between the number of trees and the granulometric texture of soils ($R=0.64$) than in young stands where pine undergrowth prevails (figure 4). In post-pyrogenic plantations with a predominance of deciduous species, there is a linear dependence of the number of all species undergrowth on the granulometric texture of two types of soils: fresh sandy loam and peaty soil (figure 4). For the pine and spruce undergrowth in these plantations, a significant correlation with soil conditions was revealed: for pine $R=0.71$, for spruce $R=0.69$. A stronger correlation is observed for deciduous species. For birch, the correlation coefficient is $R=0.85$, for aspen $R=0.86$, which indicates more favorable conditions for post-pyrogenic regeneration of deciduous species on these soil phases (figure 4).

**Figure 4.** Influence of the particle size distribution of the soil on the quantity of regeneration spruce, pine, birch and aspen in stands dominated by deciduous species, where, 2- Sandy loam humid soil; 6- Peaty soils.

### 4. Conclusion

In forest sites affected by ground fires, there is a multidirectional formation of coniferous and deciduous young stands depending on the state of the soil complex. The research suggests that this is due to different indicators of the granulometric texture of the soil.

In general, at this stage, deciduous species do not have a large competitive impact on spruce and pine undergrowth. Timely regulation of the number of deciduous species allows forming stands with a significant part of coniferous species on the soil phases under consideration.

Analysis of post-pyrogenic regeneration of tree species allows concluding that there is a steady process of coniferous undergrowth formation since there is a sufficient number of spruce and pine undergrowth of large and medium categories. Timely removal of deciduous trees will allow in the future forming mixed spruce-pine plantations or mixed coniferous-deciduous stands dominated by spruce and pine.
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