Restoration of tree species on fallow lands of North-West Russia

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Abstract. The study of the regeneration processes on the postagrogenic lands in different landscape conditions of the North-West region was carried out. The main factors for the successful regeneration of spruce and pine on postagrogenic lands are the distance to the source of seeds and the amount of deciduous tree-shrub species. The significant influence on the regeneration of tree species on the sandy postagrogenic lands has a pyrogenic effect. Depending on the landscape characteristics, the process of forming the species composition of the stand will have its own succession line of development. The growth of spruce and pine in most plots is more intensive than on the lands of the forest fund. It is necessary to regulate the regeneration processes of economically valuable species in order to involve the postagrogenic lands in economic circulation.

1. Introduction
The postagrogenic lands of the taiga zone of the North-West of the Russian Federation are at different stages of succession, which is manifested in the ecological and floristic characteristics and in the connection of certain plant species with the severity of microrelief [1-6]. In terms of landscape, the set-aside lands are associated with different types of agricultural landscapes, differing in composition and genesis of soil and soil-forming rocks. Consequently, they will also differ in their granulometric composition, topography, water and physical properties of soil, type of water supply, causes of water logging of the soil, which causes their different potential fertility and, as a result, different natural-resource potential of productivity of agricultural crops and forest plantations [7-11]. According to the stage of plant succession, the laylands can be divided into three groups; meadow, shrub, forest. The studies conducted by a number of authors allow identifying certain options for the development of succession processes depending on landscape characteristics [12-14]. In the Nonchernozem belt, even a short-term suspension in tillage, mowing or grazing of livestock ends with the regeneration of trees and shrubs in agricultural areas. Especially rapidly such a seizure takes place in small fields, interspersed in the lands of the State Forest Fund fields and haymaking. The lack of information and the disconnectedness of data on the course of the forest formation process on the former agricultural lands do not allow the formation of a scientifically-based system of measures for the rational management of forestry on these lands [5, 8]. The purpose of the study was to assess the success of the regeneration of spruce and pine in different landscape conditions on the postagrogenic lands of the study region.
2. Experimental part

The objects of study were three plots of laylands in three landscapes of the North-Western region of Russia. Two landscape districts of the Izhora Plateau and the Oredezhsky-Luzhsky are situated in the Leningrad Region [9, 10]. The landscape of the Izhora Plateau is composed of limestones, dolomites and marls of the Ordovician period, sometimes reaching the surface. The surface of the plateau is flat, occasionally with encountered low moraine hills, kams, as well as karst depressions. Drained undulating and slightly undulating plains on carbonate bedrocks are overlain by moraine carbonate boulder loams. These locations are most characteristic of the landscape region of the Izhora Hills. Due to the high saturation of soils with carbonates, fertile carbonate-humus mafic soils were formed in this landscape. In general, the area occupied by agricultural land is about 30% of the total landscape area and has a long history of use. However, there is a significant amount of finely contoured areas of the fields almost from the very surface saturated with fragments of carbonate rocks of various sizes that have not been used for more than 20 years in active agricultural circulation. The Luzhsko-Oredezhsky landscape is a lowland morainal marshy plain with patches of moraine hills and lake-glacial depressions. Heights up to 100 m have very smooth drops here. In general, the territory of the district is characterized by a gently undulating plain relief. The agricultural landscape development is low - about 15% of the total area. The relatively high soil fertility and low rubbly moraine were factors contributing to significant agricultural development of such locations. Now motley-grass and grass – motley meadows on sod-gley soils grow on them. At present, the overgrowing of trees and shrubs is carried out on drained moraine plains on previously cultivated boulder sandy loams and clay-bearing soil. Abandoned at various times, plots of agricultural lands are covered mostly with small-leaved grass and tall grass forests.

In the northern part of the Pskov region is located the Pskov-Luzhsky landscape [9, 10]. The relief of this geological formation is very diverse and consists of medium-high, low-drained, flat-dulating ice-lake plains, composed of fine and medium-grained sands and clays, with podzolic, sod-podzolic soils under agricultural land. On the slopes of the hill, there are hilly-kame plains with a predominance of light-textured rocks with weakly and superficially podzolic soils. In general, the elevated relief is hilly, and at the same time cut into separate parts by the river beds and streams. Agricultural development of the most territory under study is 45-65%, forest cover - 20-30% with a great dislocation of forests, swampiness - up to 5%. More than half of the agricultural land of this landscape are in various succession stages of vegetation. In order to account the number of undergrowth using circular sampling, circular platforms of 10 m² or R = 1.78 m were laid [15, 16].

Discount areas were laid at the same distance from each other in a free move using at least 3 moves. The discount areas were laid using a 178 cm long pole. The center of the next discount area was installed using the same pole, by moving it forward for two lengths.

In accordance with generally accepted classifications the undergrowth was divided:

1) by height – into 3 categories of coarseness: small – up to 0.5 meters, medium – 0.51-1.5 meters and large – more than 1.5 meters;

2) by density – into three categories: rare – up to 2 thousand, average density – 2-8 thousand, dense – more than 8 thousand plants per 1 hectare;

3) by distribution in area – into three categories depending on occurrence (occurrence of undergrowth is the ratio of the number of discount areas with plants to the total number of discount areas established in the study plot or the cutting area, expressed as a percentage): uniform – occurrence over 65%; uneven – occurrence of 40-65%; group (at least 10 pieces of small or 5 pieces of medium and large copies of viable and close undergrowth).

The resulting material was processed using the methods of mathematical statistics according to the following formulas:

1) The number of undergrowth per hectare, pcs ha⁻¹ (Mₘₐ):

\[ Mₘₐ = \frac{\sum N_{1000}}{nS}, \]  \hspace{1cm} (1)
where, \( \Sigma N \) is the total number of undergrowth on all discount areas, taking into account conversion factors, \( n \) is the number of discount areas, \( S \) is the area of one discount area (10 m\(^2\)).

The total number of undergrowth, taking into account the recalibration of small and medium-sized undergrowth into large, specimens:

\[
\Sigma N = 0.5 \Sigma N_s + 0.8 \Sigma N_m + \Sigma N_l
\]

where, \( N_s \) – the number of small undergrowth, specimens; \( N_m \) – the number of average undergrowth, specimens; \( N_l \) – the number of large undergrowth, specimens.

Occurrence rate \( \tau \) %

\[
\tau = \frac{n_1}{n} \times 100
\]

where, \( n_1 \) – is the number of discount areas where the undergrowth occurred.

2) The homogeneity coefficient – HC. This indicator shows the placement of undergrowth by area. If \( HC < 1 \), the distribution of undergrowth is random, if \( HC \approx 1 \) the distribution is uniform, if \( HC > 1 \) this is the group distribution.

\[
HC = \frac{\sigma^2}{\bar{m}^2}
\]

In the course of the study, we determined the area of plots with the regeneration of forest cover and the distance to the sources of seeds for the regeneration of spruce and pine.

In the process of studying the soil complex, the method of soil cuts and diggings was used with a description of soil horizons. Determination of particle-size composition (N A Kachinsky method). The humus content was determined by the method of I V Tiurin, salt extract pH - by the potentiometric method [17].

3. Results and discussion

Processes of forest cover regeneration on the set-aside lands have their own characteristics, depending on the soil and hydrological conditions of a particular landscape [5, 10, 12].

Two plots of the laylands were studied under typical conditions of the Izhora plateau landscape, directly adjoining the forest wall. The latter were used as haymaking and grazing. The term of laying is 17-20 years. The adjoining wall of spruce-pine forest served as a source of seeding.

Soils under unused agricultural land in this landscape have a former arable humus-accumulative horizon with a capacity of 20–25 cm with a well-expressed blocky-lumpy or lumpy-walnut structure, boiling away from hydrochloric acid solution (HCl). Below follows the horizon B (BC), saturated with fragments of limestone and dolomite of various sizes and less often contains small boulders of crystalline rocks. From a depth of 20–30 cm, the skeleton fraction content is at least 30%. The humus content in the soil of the first plot is 7.8%, and the pH is 6.4. In the second plot, the humus content is 8.01%, pH - 6.6%. The high content of humus in the soil is associated both with the previous economic impact in the past period of soil development, and with the specifics of the process of its formation under conditions of close laying out of carbonate soil-forming rock. The obtained data from the study shows that the process of reforestation in the studied plots is predominantly with a predominance of conifers (see Table 1). The predominance of pine in this area is probably due to less moist conditions of growth, since the soil is sandy-loamy, as well as a reliable source of seeding in the adjacent maternal tree stand - the share of pine is 30% of the plantation composition. From the data obtained it is clear that in the process of reforestation the predominant species are pine and birch. Spruce can later go into the same story with these species. The share of hardwood - birch is less than coniferous. A coniferous deciduous plantation is formed. Uneven placement of undergrowth is probably due to microelevations in this plot, which were formed as a result of tillage in previous years.

In the second studied plot spruce prevails among conifers. The share of pine, with a very small number of seeding trees, is 25% of the total number of regenerated undergrowth. This shows its high competitiveness in such conditions (see Table 1). Among the hardwoods dominate shrub willow and
gray alder. Conifers are best regenerated at a distance of 25 meters from the forest wall, but as they move away, their share decreases significantly. The presence of a greater amount of spruce undergrowth is associated with moister growing conditions, since the soil in this plot is an average loam enriched with organic substance. The placement of spruce undergrowth in this plot was more evenly distributed over the plot than in the first studied plot, which also seems to be related to soil and hydrological conditions.

In general, it should be noted that the natural regeneration of tree stands on the former postagrogenic lands is much better than in the conditions of cutting in these conditions of growth [10]. Currently, there is a successful regeneration of coniferous species on laylands of the studied landscape, which is associated with a small area of non-cultivated fields due to the high degree of their stony gravel limestone. The arable horizon formed as a result of economic activity, as well as the carbonate parent rock, make it possible to form highly productive coniferous plantations, which is observed in ripe spruce plantation. The formation of coniferous stands will continue on the postagrogenic soils of the Izhora Plateau, probably through the stage of mixed spruce stands with different shares of pine and hardwood.

Table 1. Indicators of natural regeneration on test plots in the landscape of Izhora plateau.

| Test area (ha) | Species | Average | homogeneity coefficient (HC) |
|---------------|---------|---------|-----------------------------|
| #1 (≈3 ha)    | Pine    | 7       | 150, 25, 1350, 80, 0.7      |
|               | Spruce  | 6       | 100, 17, 420, 50, 0.6       |
|               | Birch   | -       | 300, -, 1320, 36, 0.6       |
|               | Willow  | -       | 100, -, 64, 10, 0.2         |
| #2 (≈3 ha)    | Spruce  | 7       | 100, 14, 2060, 90, 1.3      |
|               | Birch   | 7       | 155, 26, 520, 45, 0.80      |
|               | Willows | 300     | 40, 25, 0.50               |
|               | hrub    | 100     | 1000, 10, 0.90             |
| Gray alder    | 200     | 1000, 14, 0.90               |

In the Luzhsko-Oredezhsky landscape region, three plots of laylands, previously used as arable land with a laying out period 30-35 years, were studied. The soils in the plots of sod-weakly podzolic medium cultivated and deep-tillage sandy loam on moraine boulder loam are characteristic for the studied region. The share of such soils in the total area of agricultural land is up to 20%, and up to 35% of the forested land in the Luzhsko-Oredezhsky landscape region [9, 10]. The humus content in the studied plots is 2.7 -3% in the former 30cm arable horizon, and the pH is 5.3-5.8.

The test plot No. 3 is located at a distance of 100 m to the wall of ripe spruce-pine-birch forest. In this area, the prevailing species is spruce with group placement, as indicated by the coefficient of homogeneity. Tree willow is represented by a large number of trees arranged in groups. Birch occupies a middle position in numbers on this tested plot. Pine and oak are represented by single trees (Table 2).
On the test plot No. 4, the prevailing species is also spruce with group placement. Willow is represented by a slightly smaller number of trees. Birch and aspen are quantitatively represented almost the same and have curvy placement, and pine occurs less often on this plot (Table 2). The greatest number of spruce trees in this plot is caused by direct adjoining of the two sides of this plot to the wall of spruce-pine stand.

In the test plot No. 5 there is a smaller amount of coniferous undergrowth, which is probably caused by the greatest distance of 150-170 m from the forest wall. However, the rare and curvy-like placement of hardwood allows spruce to successfully grow under the canopy of hardwood. This is indicated by the coefficients of occurrence and homogeneity of these species. Pine is not represented by a large number, as in the previous plot, which is associated with a large number of hardwood species competing for photosynthetic resources for these species.

In general, for these plots it is necessary to note the clear dependence of the number of regenerated spruce on the source of seeding. A large number of shrub willow is an indirect confirmation of sufficient moisture. This is confirmed by the observed signs of weak gleying below the located soil horizons under the former arable horizon in these plots.

In general, a good growth along the height of spruce and pine is observed on the studied plots in comparison with similar plantations on forest lands [13]. In the forest fund, the best-growing forest cultures at a given age are shorter in the studied region [5]. Only smaller indicators of height and increase of spruce are different on the plot No. 4. This is due to the large number of willow and birch on this plot and shading of this species.

The studied plots of laying out arable lands of sod-podzolic soils, most represented in the Pskov-Luzhsky landscape and confined to the elevated parts of the plains and the upper parts of the slopes of positive landforms. Due to the high bioproductivity, the arrays of varieties of sod-podzolic soils were previously developed for agricultural land in this landscape. The term of laying out of these lands is 20-25 years. The soils in the studied plots are sod-podzolic sandy loam on sands. The presence of a well-marked arable horizon with a capacity of 35-45 cm indicates a long-term economic use and application of organic fertilizers based on peat. The humus content in these soils is 1.4–2.5%, and the pH is 4.7–5.5. The test objects directly adjacent to the source of seeding - forest belts consisting of Scots pine. It is necessary to note the pyrogenic effect of spring fires on the regeneration of pine in these laylands. In the studied plots, annual damage of a part of the natural regeneration of tree species by fire is observed. However, spring fires caused by anthropogenic factors allow subsequent

| Test area (ha) | Species | Average age Aav, years | height Hav, cm | increase in height Zav, cm/year | number trees ha⁻¹ | occurrence τ, % | homogeneity coefficient HC |
|---------------|---------|------------------------|----------------|-------------------------------|-------------------|-----------------|---------------------------|
| #3 (=1.5 ha)  | Spruce  | 4                      | 41.0           | 10.4                          | 3142              | 91.6            | 2.3                       |
|               | Birch   | -                      | 1198           | -                             | 2212              | 62.7            | 3.8                       |
|               | Aspen   | -                      | 780.0          | -                             | 48                | 3.6             | 0.1                       |
|               | Willow  | -                      | 1000.0         | -                             | 2807              | 43.4            | 5.2                       |
|               | Alder   | -                      | 873.6          | -                             | 133               | 6.0             | 3.6                       |
| #4 (=1.5 ha)  | Oak     | -                      | 25.0           | -                             | 84                | 4.8             | 2.0                       |
|               | Pine    | 10                     | 188            | 18.8                          | 92                | 10.0            | 0.9                       |
|               | Spruce  | 10                     | 69.3           | 6.9                           | 4642              | 84.0            | 9.1                       |
|               | Birch   | -                      | 434            | -                             | 2360              | 54.0            | 6.7                       |
|               | Oak     | -                      | 200            | -                             | 260               | 18.0            | 0.5                       |
|               | Willow  | -                      | 628            | -                             | 4460              | 98.0            | 1.4                       |
generations of pine to regenerate [5, 12]. Depending on the number of effects of fire, virtually pure stands of various densities are formed (see Table 3). On the test plots No. 5-6, there is currently a successful regeneration of pine, and hardwood species are minimally present. Placement of pine in the area of the studied plots of the former arable land is even, as indicated by the data of the obtained coefficients of homogeneity and occurrence. The proportion of pine trees damaged by fire and dead trees is 10-15% of the total number of trees. This is probably due to the fact that xeromorphic vegetation species that do not form a large source of fire prevail in the live ground cover. On the plot No. 8 one can observe the further possible regeneration of pine stand on the postagrogenic soils under the conditions of this landscape. This plot is located on a flattened elevation. As a result of postpyrogenic impact for 15 years, pine stands have been formed with pronounced two generations. In the plantation, there is a partial impact of the lower fire of a 3-5 year period on the trunks of trees. The number of dead trees is 1-3% of the total. The stock of the first story is about 80 m$^3$ with an average height of 14 m and a diameter of 10 cm. At the periphery of this stand, there is a regeneration of spruce. In the intervals between the main story there is a regeneration of the younger generation of pine due to the low projective cover of grassy vegetation. The share of hardwood is not large, mostly willow in the depressions.

**Table 3.** Characteristics of undergrowth by species at test plots in the Pskov-Luzhsky landscape.

| Test area (ha) | Species | Average age $A_{av}$, years | Height $H_{av}$, cm | increase in height $Z_{av}$, cm/ year | number, trees ha$^{-1}$ | occurrence, $\tau$, % | homogeneity coefficient (HC) |
|---------------|---------|----------------------------|--------------------|--------------------------------------|-------------------------|------------------------|-----------------------------|
| #6 (<4 ha)    | Pine    | 6                          | 120                | 20                                   | 2709                    | 95.0                   | 1.1                         |
|               | Birch   | -                          | 300                | -                                    | 188                     | 10.0                   | 0.5                         |
| #7 (<6 ha)    | Pine    | 7                          | 150                | 25                                   | 1435                    | 80.0                   | 0.95                        |
|               | Spruce  | 10                         | 200                | 20                                   | 77                      | 10.0                   | 0.2                         |
| #8 (<4 ha)    | Pine    | 14                         | 1300               | 85                                   | 3600                    | 98.0                   | 1.8                         |
|               | Willow  | 60                         | 60                 | 50                                   | 50                      | 10.0                   | 0.1                         |
|               | Pine    | 7                          | 220                | 32                                   | 1471                    | 50                     | 0.9                         |
|               | Spruce  | 7                          | 150                | 25                                   | 50                      | 10                     | 0.4                         |

4. Conclusion

A study of regeneration processes on the postagrogenic lands allows us to make a number of conclusions on the direction of these processes in the study region:

- Landscape conditions determine the quantitative indicators of the regeneration of certain breeds on the set-aside lands.
- Depending on the distance from the source of the seed, the number of spruce and pine undergrowth varies on the areas of the postagrogenic lands.
- On the fertile postagrogenic soils, the growth of coniferous undergrowth will be hampered by the active growth of the deciduous tree-shrub vegetation.
- On the sandy soils of the former agricultural lands, as a result of the pyrogenic impact, it is very likely that uneven-aged pine stands will form.
- Regulating the succession processes, it is possible to form economically valuable plantations of spruce and pine, differing in more active growth in comparison with tree stands growing on forest lands.

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