The growth of geographical crops of Scots pine on drained lands

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Abstract. The research analyzes observation materials and condition assessment of 100-year geographical Scots pine forest cultures created in 1913 by professor Ogievsky V D on drained lands of the Okhta forestry territory to study the intensity of Scots pine trees growth depending on the seeds origin. The planting material was grown from seeds collected in the northern, southern, eastern, southwestern and central parts of Russia. The growth of Scots pine cultures was studied and changes in wood stock, trees amount, annual increments, influence of meteorological factors on radial increments were analyzed depending on the origin of the planting material. The results of research show that sustainable and highly productive cultures can be grown from seeds of northern and eastern regions of Russia.

1. Introduction
Scots pine is one of the most valuable forest-forming species, which contributes significantly to enhancing reforestation and afforestation. It is possible to reduce the growing period by creating forest plantations. The most important factor for reducing the technical maturity age of trees using plantation forestry techniques is the technology of creating forest crops, providing an optimal temperature regime and soil moisture, as well as the quality of planting material with a hereditary predisposition for intensive growth [1-6].

Geographic cultures of offspring of different Scots pine climatypes growing in the same conditions and of the same age make it possible to trace the dynamics of offspring development, determine intraspecific differentiation and identify populations and forms promising for target use outside of natural habitats [7,8].

One of the founders of research on the influence of geographical origin of seeds on forest growth is Ogievsky V D. Under his leadership during the period from 1910 to 1916 a large number of experiments were carried out on the territory of Okhtinskaya dacha, now Okhta educational and experimental forestry.

The most studied are geography pine crops created in the 8th quarter of in 1913 at Okhta forestry. The geographic pine plantations created in the 8th compartment of the Okhta forestry in 1913 are most studied object of this series [9-12]. The purpose of this work is to study the growth of Scots pine crops on drained lands depending on the geographical origin of seeds.

2. Methodology
Geographic crops were laid by Prof. Ogievsky V D to study the growth of Scots pine depending on the
geographical origin of seeds. The area designated for crops was a clearcut of 1910. The area outlined for crops was ditched and fenced in autumn 1912. Tillage was carried out in the spring of 1913 and consisted in preparation of “closed holes” of 40×40 cm, by transferring soil from each successive one to the previous one. The planting location is 142×35 cm, which is 20,000 pcs/ha. Planting was carried out from 28 May to 3 June 1913. In each planting place 2 one year seedlings were planted separately under Kolesov’s sword. Planting material was grown from seeds of different origin at the Forest Institute nursery.

Given that by now the rows characterizing individual regions have not survived, the characterization of pine crops is given according to the geographical origin of seeds of the European part of Tsarist Russia: Northern region (Olonets region currently Karelia), Eastern region (Vyatka currently Kirov region), Southern (Volyn region), South-Western (Grodno region), Central (Vladimir region). As a control, two rootstock plots were studied in drained (KU-1) and non-drained areas (KU-2), with identical soil conditions.

Forest type in the sample plot is fresh bilberry pine forest. The area is geomorphologically characterized as plain with normal and impaired drainage. Soils are coarse-humus medium and strongly podzolic, sandy loam and loam. Pine stands with admixture of birch and spruce predominate. Undergrowth consists of the sample of spruce of varying density. Medium-dense undergrowth consists of mountain ash, juniper, willow, buckthorn. The vegetation cover comprises by Vaccinium myrtillus L., Calamagrostis phragmitoides Hartm., at least Vaccinium vitis-idaea L., Rubus saxatilis L., Maianthemum bifolium (L.) Schmidt F W, Melampyrum nemorosum L., mosses: Hylocomium, Pleurozium, Dicranum.

During the whole period of observations no thinning was carried out on the studied crops. Groundwater levels in boreholes and water depths in channels were measured from the top of piles that were driven at least 0.6 m into the mineral soil near each borehole. The surface of the piles was periodically levelled, taking into account the recommendations of Vompersky S E [13]. In the process of hydrological studies in forests, observations during the vegetation period are the most important. It is known from the works of Veretennikov A V [14] and Orlov A Y and Koshelkov S P [15] that flooding of pine, spruce and birch roots for more than 4-5 days leads to their die-off due to a lack of oxygen and a decrease in the growth of stands. For these reasons, measurement of groundwater levels during the growing season (May-September) at stationary sites was carried out every 5-10 days. During the rest of the time groundwater levels were monitored every 15 days.

Taxation indices of the studied crops were determined by generally accepted silvicultural methods. Indices of geographical crops were measured at the age of 44, 57, 78, 95, 102 years. The results of taxation indices are presented in graphs and tables. Also, 9 trees of Scots pine were selected on the experimental plots. Core samples were taken from 72 trees with a Pressler drill. The radial increments of each sample were measured using LINTAB and TSAP Win software. Damaged, diseased, and shrunken trunks were noted in the corresponding columns of the table.

No soil surveys have been undertaken and no transects have been plotted, as a soil map is available for the entire Okhta forestry area. Assessment of sanitary condition was conducted according to the current regulations with division of trees into 6 categories: 1 – healthy, 2 – weakened, 3 – severely weakened, 4 – decayed, 5 – current year dead wood, 6 – dead wood of previous years. The criteria for assessing the possibility of using these climatypes in the study area are: survival rate, growth parameters, stem wood stock [3,7,16,17].

3. Literature review
From 1903 to 1916, 55 hectares of crops were planted and sown at the Okhtinskaya dacha – mainly pine, to a lesser extent spruce and in a small area Siberian larch (0.8 ha) and oak (0.4 ha). The first drainage works of the Okhtinskaya dacha were carried out in the 1940s by the Northern Expedition of I.K. Avgustinovich, who canalized and cleared the streams at the dacha, which was then called the “Okhta swamp”. The density of the soil of the upper horizons T and A1 is 0.1551 g/cm² and 0.6256 g/cm² respectively, which is 10 to 6 times less than the density of the lower horizons B and C.
Consequently under these conditions water flow into canals of drainage network is hampered and is carried out mainly through upper 20 cm layer of soil. During 1878-1879 two natural rivers, Zhernovka and Karaula, (“main highways”) were canalized and 30.8 km of channels were dug. The whole Okhtinskaya dacha drainage project was finalized by Tovstoles D P [18] in 1909, preceded by a surface leveling of more than 75% of the dacha area.

During 1941-1945 period, most of the canals were deformed, crossed by ditches, trenches, partially filled in. In 1941 an anti-tank ditch of 2.5 km in length, 4-5 m wide at the bottom and 2-3 m deep was dug on the forestry territory. After reconstruction, the anti-tank ditch became a main canal, which drained a large part of the territory of Zhernovsky forest district and improved the water regime of the soil and studied pine crops.

Since 1972 a large-scale program for creation and study of geographic cultures of main forest-forming species has been carried out in Russia. This experiment has no analogues in the world in terms of diversity and origin of species and area [19]. Observations of soil and groundwater levels were carried out using specially constructed observation wells (boreholes). The boreholes were arranged according to the SNIGM guidelines [20] in order to establish the depth of groundwater in stands of different productivity. Since 1972 a large-scale program for creation and study of geographical cultures of the main forest-forming species begins in Russia. This experiment has no analogues in the world in terms of the diversity of species and their origin as well as the area of created forest plantations [21,22].

4. Results

The criteria for evaluating the growth of crops from seeds of other regions are the sanitary condition of plantations, the number of trees per hectare, the intensity of growth and stock. The sanitary condition of trees is presented in table 1.

| Geographical areas | Tree division by state categories, % | Average |
|--------------------|-------------------------------------|---------|
| northern           | 34 48 9 3 2 2                      | 2.03    |
| central            | 12 38 25 16 1 8                   | 2.80    |
| southern           | 19 12 23 30 7 9                   | 3.21    |
| southwestern       | 12 39 23 12 6 8                   | 2.85    |
| eastern            | 41 31 18 6 0 4                    | 2.05    |

Crops of northern and eastern climates have the best indicators of tree condition 72-82% belong to the first (healthy) and second (weakened) category, with an average category of 2.03...2.05. According to the data 25% of trees of southern and central regions belongs to the third category (severely weakened) with an average category of 2.8...3.21. The dynamics of tree density per hectare is shown in figure 1.

By the age of 102 years, preservation of the studied crops in the conditions of Okhtinskaya dacha estate of St. Petersburg is in the range of 1.8-2.5% of the initial density (number of planting places). Seed crops from the northern area have the best performance, the number of trees decreased almost uniformly 10-15% over 10 years. A strong decrease in the number of planted trees (80% for 10-12 years) was observed in pine plantations from seeds of the southern and southwestern regions. The dynamics of crop height progression is shown in figure 2.

Growth intensity in all studied variants did not have large deviations. In the first half of the observation period, the average height by 1-2 meters was greater in pine trees grown from seeds of central area, and in the second half of the period the height by 1-2 meters less than the average variant with cultivation of progeny of northern and eastern areas. In the second half of the pine plantation growing period, the height of trees from seeds of southern and southwestern areas was greater. The dynamics of growth in the stock of pine crops with age increase is shown in figure 3.
Wood stock per 1 ha in all variants of tree plantations reached the range of 390-450 m$^3$/ha. Due to greater preservation, plantations from the seeds of the northern, central and southwestern areas show the best indicators, 449-455 m$^3$/ha. The least amount of trunk wood is observed in plantations created from the progeny of the southern and eastern regions. Taxation characteristics of Scots pine crops are presented in table 2.
Figure 3. The dynamics of growth in the stock of pine crops with age increase distributed by geographical areas.

Table 2. Taxation characteristic of the 102-year geographical cultures of pine planted under the leadership of prof. Vasili Ogiyevsky in Okhta educational and experimental forestry.

| Region     | Average parameters of growth | Quantity of trees, unit/ha | Preservation, % | Stock, m³/ha | Trunk volume, m³ |
|------------|------------------------------|-----------------------------|-----------------|--------------|-----------------|
|            | H, m                         | D₁₂, cm                     |                 |              |                 |
| northern   | 28.3                        | 29.7                        | 505             | 2.5           | 449             | 0.888           |
| central    | 27                          | 31                          | 508             | 2.5           | 455             | 0.897           |
| southern   | 30                          | 32.8                        | 360             | 1.8           | 391             | 1.086           |
| southwestern | 30.2                      | 33.3                        | 406             | 2             | 453             | 1.116           |
| eastern    | 28                          | 30.5                        | 420             | 2.1           | 403             | 0.960           |

Based on the data of table 3, we can say that in spite of less preservation of cultures of southern climatypes of they have greater trunk volume per tree 1.086…1.116 m³.

Table 3. Average value of radial increments of trees by age groups.

| Age groups | Average value of radial growth of trees, mm |
|------------|--------------------------------------------|
|            | central | southwestern | northern | eastern | southern | dried plot | undried plot |
| 0-20 years | 2.15    | 3.69         | 2.65     | 2.76     | 3.47     | 3.03       | 1.61         |
| 21-40 years old | 0.88    | 2.07         | 1.62     | 1.36     | 1.60     | 1.3        | 1.50         |
| 41-60 years old | 0.98    | 0.98         | 0.92     | 0.74     | 0.94     | 0.78       | 1.11         |
| 61-80 years old | 0.85    | 0.45         | 0.60     | 0.75     | 0.71     | 0.7        | 0.76         |
| 81-100 years old | 1.03    | 0.58         | 1        | 0.83     | 0.66     | 0.64       | 0.64         |

Having analyzed the results of increments average values for periods of 20 years, we can say that at the beginning of life, 0-20 years, radial increments of geographical crops on drained lands exceed the same indicator for non-drained, in some cases (Grodno) twice. However, having compared indicators
of the subsequent 20-year periods, we cannot say that radial increments of the studied crops have significant differences from the course of growth of the native stand (Control). The average groundwater table for the growing season in Okhta forestry is presented in table 4.

**Table 4.** Average depth of groundwater during vegetation period, cm.

| Site index | Stock, $m^3$ | Channel spacing, m | Ground water level | amplitude |
|------------|--------------|--------------------|--------------------|-----------|
| II         | 300          | 110                | 46                 | 87        | 16 | 71 |
| II         | 300          | 110                | 32                 | 89        | 7  | 82 |
| I          | 370          | 110                | 40                 | 89        | 6  | 83 |
| III (control) | 220          | 240                | 13                 | 61        | -7 | 68 |

Sign "-" means that the groundwater level was higher than the soil.

On given plots water permeability of top 40 cm horizons of drained soils was 75-309 m/day, that is they are water permeable, and lower horizons are almost watertight. Water outflow is observed practically along upper soil horizons. The neighboring site, where the distance between the dehumidifiers is 240 m, is practically not drained and waterlogging processes are observed, was chosen as a control.

Long-term studies of rainfall penetration under the canopy of pine stands using soil rain gauges show that on average 379 mm of precipitation falls in this area during the growing season (from May to September). Under these conditions, stands of Scots pine of I and II quality class retain about 24% of precipitation on the crowns, which is 90 mm during the growing season. This exceeds the monthly norm of precipitation by 20%, which also contributes to drainage of temporarily excessively wet lands and improve the water regime of mineral-hydromorphic soils. Total evaporation on such plots is comparable with amount of precipitation. On the control plot, with III boinitet (yield class) and less completeness, only 8% of precipitation is detained in crowns, total evaporation is lower which results in moisture accumulation and waterlogging.

On average, during vegetation period groundwater is at the depth below 40 cm from the soil surface, releasing the whole root-inhabited soil layer from flooding and underflooding. In dry periods, the groundwater table usually drops below 90 cm. When comparing with the control plot, which is almost not drained, we can see that on the control groundwater table on average during the growing season is at a depth of 13 cm, undermining the roots of Scots pine. In the periods after the rains, groundwater is even higher than the soil surface by 7 cm, flooding the root systems. On the control plot water regime of soli is not favorable, there is waterlogging, and therefore the stock of Scots pine reaches only 220 cubic meters. Statistical processing of multi-year data on groundwater levels and precipitation showed an error of no more than 5%.

At an optimal groundwater level and optimal water regime in the conditions of the Leningrad region, on heavy soils with mechanical composition, it is possible to grow high-yield plantations of Scots pine of I and II quality classes with a stock of more than 360 at the age of 100 years (table 5).

The data of correlation analysis showed that the studied climatypes under Okhta forestry conditions respond differently to changes in meteorological factors at different age stages. In the first 20 years of life most of climatypes negatively react to amount of precipitation during vegetation period. In the next 40 years climatypes of south-western and eastern region and control areas have more pronounced relationship with precipitation.

Leningrad region is a zone of excessive moisture, where the main limiting factor for plant growth is heat. The results of radial increments and temperature correlation analysis showed that climatypes of northern and central regions were the least dependent on temperature regime [4-6].
Table 5. Correlation indices of average radial increment by age groups with temperature and precipitation during vegetation period.

| Age  | central | southwestern | northern | eastern | southern | dried plot | undried plot |
|------|---------|--------------|----------|---------|----------|------------|-------------|
| Precipitation |
| 20   | -0.57   | -0.29        | -0.48    | -0.08   | 0.08     | 0.12       | -0.45       |
| 40   | 0.22    | 0.3          | -0.34    | 0.16    | 0.15     | 0.35       | 0.38        |
| 60   | 0       | 0.31         | 0.22     | 0.25    | -0.31    | 0.09       | 0.15        |
| 80   | -0.31   | -0.11        | -0.33    | 0.07    | -0.1     | -0.34      | -0.29       |
| 100  | -0.20   | 0.12         | -0.08    | 0.09    | 0.02     | 0.12       | -0.15       |
| Temperature |
| 20   | -0.17   | 0.57         | 0.22     | -0.17   | -0.18    | 0.54       | 0.88        |
| 40   | 0.04    | 0.48         | 0.15     | 0       | 0.39     | 0.25       | -0.42       |
| 60   | -0.06   | -0.28        | 0.12     | 0.27    | -0.03    | -0.14      | 0.2         |
| 80   | -0.08   | -0.09        | 0.48     | 0.12    | -0.02    | -0.36      | 0.2         |
| 100  | 0.49    | -0.17        | -0.21    | -0.14   | 0.18     | 0.18       | 0.52        |

5. Conclusion
To create stable and productive stands of Scots pine in the Leningrad region, it is advisable to use seeds of the northern and eastern regions of Russia. The use of seeds of southern climatypes is a promising method of creating forest crops to produce technical wood with a shorter growing season. However, crops from seeds of these areas require more agronomic care. With an optimal groundwater level and optimal water regime of soils in the conditions of the Leningrad region, it is possible to grow highly productive plantations of Scots pine on heavy soils in terms of mechanical composition.

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