Radial growth of Scots pine and Norway spruce stands as an indicator of soil and environmental conditions

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Abstract. The study presents an analysis of radial growth of Scots pine and Norway spruce trees growing on drained soils formed on varved clays at the sample sites of the Lisino Experimental Forestry (Lisino). Based on dendrochronological studies in Lisino, it has been found that the radial growth of Scots pine and Norway spruce is a sensitive indicator of changes in the soil water regime, climate, and phytocenotic relationships. On the basis of the character of tree-ring width growth, the growth charts allowed distinguishing zones with close to average growth values, as well as with increased and decreased values of radial growth. The cyclical pattern of tree ring width is well expressed in the successive change of zones. The availability of dendrochronological research materials with precise spatial and temporal reference makes it possible to organize monitoring of radial growth of trees as an indicator of changes in climate and habitat conditions.

1. Introduction

Global climate change will inevitably affect the productivity of forest plantations and the carbon balance of forest ecosystems [1, 2]. In order to predict the extent of such impact, it is necessary to organize long-term soil monitoring of forest ecosystems [3]. The first step in this direction is to analyze the relationship between growth and development parameters of trees and the overall soil and climatic conditions of the areas. For this purpose, dendrochronological method of research is widely used [4-6]. This method makes it possible to carry out retrospective analysis of growth dynamics of trees of different age classes with a wide growth interval from decades to 150 and more years [7].

The problem of assessing the relationship between tree growth and climatic characteristics based on the dendrochronological method has long attracted the attention of researchers [8-10]. Significantly fewer works touch upon the impact of soil and environmental conditions on the dynamics of annual growth of conifer stands. Despite the large number of works on this topic, the problem is far from being solved. At least three reasons for this can be identified. Firstly, it is the lack of long-term series of observations of climate conditions. Secondly, it is the lack of materials of on-site observations of soil regimes. Thirdly, there is insufficient analysis of the influence of anthropogenic effects on forest ecosystems (drainage, acid rains, thinning of forests, etc.).
This calls for organization of long-term forest, soil and environmental monitoring in conjunction with the climate conditions. A promising area for this task is the Lisino Training and Experimental Forestry (Lisino) located 60 km south of St. Petersburg [11]. Its advantages as a soil and environmental testing ground include: forest ecosystems typical for the taiga zone of the European part of Russia; availability of archived materials of various studies of soil and vegetation cover; and the territory is well studied and documented (history of 200 years of development) [8].

The most widespread anthropogenic impact in the study area is caused by drainage reclamation of forest ecosystems.

The aim of this work is a comparative analysis of the dynamics of radial growth of Scots pine (Pinus sylvestris) and Norway spruce (Picea excelsa) on drained soils against the data of weather observations.

2. Materials and methods

The research is focused on Scots pine and Norway spruce stands on the drained soils of Lisino. Dendrochronological studies have been conducted at three sites under the supervision of Professor Boris Babikov (co-author of the article).

The first site is located in compartment 121 within the borders of the transitional bog of Sulanda, drained by open ditches in the 1940s [12]. Studies of radial growth of trees were conducted on two sample plots (SP) (SP6 and SP18) and covered the period of tree growth from 1830. SP6 site contains the forest stand formed mainly after the drainage. The age of pine trees was about 130 years during the period of the archived study (1976-1981). SP18 is at a distance of 300-350 m from drainage ditches, practically outside the zone affected by drainage works. The soils at the experimental sites are represented by Histic Gleysols (WRB [13]) on varved clays. The peat thickness is 60-70 cm.

The second site is located in compartment 3 of the Malinovsky hydromelioration station. It was laid on peaty-gley soils (Histic Gleysols [13]) of the Turovsky upland swamp drained in 1973-1977. The study of the effect of drainage on the radial growth of Scots pine was conducted at four experimental plots with different drainage efficiency (table 1). The studies at the first two plots were focused on assessing the effect of drainage on the radial growth of Scots pine trees of different age groups.

| Index | No. and characteristics of experimental plots | No of core samples | Period Age of trees (years) |
|-------|---------------------------------------------|--------------------|---------------------------|
| a     | No. 1 – normal drainage                      | 10                 | 91                        |
| b     | No. 2 – normal drainage, old trees           | 10                 | 123                       |
| c     | No. 3 – by ditches                           | 10                 | 45                        |
| d     | No. 3 – in between ditches                   | 10                 | 43                        |
| e     | No. 4 – ineffective drainage, young trees    | 10                 | 56                        |
| f     | No. 4 – ineffective drainage, old trees      | 10                 | 71                        |

The third site is located in the Parkovy compartment (No. 206) drained by open ditches. The soil cover is represented by three types of soils: Haplic Stagnosols, Stagnic Albeluvisols, and Histic Gleysols [13]. The dynamics of spruce stands of different age classes have been investigated at this site.

Dendrochronological studies were conducted in accordance with the generally accepted methods [8, 14, 15].

3. Results and Discussion

Comparative dendrochronological studies revealed a generally positive effect of soil drainage on radial growth of Scots pine at SP6 and SP18 within the first site (figure 1).
Figure 1. Annual indices (I, %), average ring-width increment, and average multiyear growth (mm) for control plots (I, II - SP18) and plots under study (III, IV - SP6) [16].

The comparison of tree-ring growth charts (figure 1) revealed a sharp increase in growth on the drained plot (SP6) from 1845 with a peak in 1860. Subsequently, the intensity of the ring-width increment of Scots pine trees decreased in the drained area to values of 2.1 mm/year. After 1905, the growth changed insignificantly. The most likely reason for this is an age-specific process. An increase in the growth of Scots pine in the drained area compared to the control area was also observed in the second half of the 20th century.

The dynamics of Scots pine stand growth was analyzed for sample plots with different degrees of drainage at the hydro-reclamation system (site 2, table 1). Analysis of changes in the growth intensity coefficients by diameter of pine trees using a linear trend [17] revealed the most intensive growth of the stand at SP1 on the soil with low peat thickness (figure 2a). The second most intensive growth was found in the stand near the drainage ditch (SP3, figure 2c). The third position in terms of growth value belongs to the SP4 stand (figure 2e) with young trees. Relatively lower growth was observed in the stand with old trees at SP4 (figure 2f) and in the stand in between ditches (SP3, figure 2d). The old stand (SP2, figure 2b) demonstrated the lowest growth rate.

Certain general patterns have been observed in the dynamics of radial growth of Scots pine trees. For 40 years since the drainage of the Turovsky bog, fluctuations in the annual ring width increment were the same at all experimental plots. A sharp increase in growth was observed at SP2 during the first 10 years. In the second decade, the growing stock increment was significant at all sites. Maximum growth was observed in the third decade (1994-2004). Since 2004, the increment decreased significantly at all experimental plots, especially at EP4. This decrease of growth can be explained by silting up of drainage ditches and subsequent deterioration of soil drainage conditions.

In the annual fluctuations of radial growth, three factors are relevant: the influence of drainage and subsequent thinning of stands, phytocenotic relationships, and weather conditions [18]. We compared
the average radial growth of Scots pine stands at the sample plots with the average daily air temperatures
over 10.0 °C for the period, average annual air temperature, and the amount of precipitation at the
Lyuban weather station. The calculation of the Pearson correlation coefficient revealed a weak positive
relationship between the radial growth of Scots pine trees and temperature for sample plots SP1, SP2,
and SP4 (for old pine trees) and a negative relationship for SP3 (near the ditch), SP3 (in between the
ditches), and SP4 (for young Scots pine trees). A weak positive relationship with the annual precipitation
was identified for SP1 and SP4 (for old trees), whereas SP 2, SP3 (by the ditch), SP3 (in between the
ditches), and SP4 (young trees) demonstrated a negative relationship.

![Scots pine growth graphs for experimental plots of site 2. The broken line shows the average growth (mm). (a) SP1; (b) SP2; (c) SP3, by the ditch; (d) SP3, in between ditches; (e) SP4, young trees; (f) SP4, old trees.](image)

Figure 2. Scots pine growth graphs for experimental plots of site 2. The broken line shows the average growth (mm). (a) SP1; (b) SP2; (c) SP3, by the ditch; (d) SP3, in between ditches; (e) SP4, young trees; (f) SP4, old trees.

At the third site, dendrological studies focused on the relationship between the growth dynamics of
Norway spruce and climate conditions over 150 years of stand growth [14]. Based on the estimation of
average ring width increments, a number of features characterizing the trend in the ring width growth
were identified. They are expressed in Z-score (figure 3).

Three zones of Z-score distribution have been identified on the basis of the timeline analysis of the
ring width growth trend: A) the growth increase close to the average value; B) an increased value of the
increment; and C) a decreased value of the ring width increment. The observed pattern in the successive
change of zones is as follows: ABCBACAC. The period of cycle duration is approximately 10-15 years.
Before 1910, the observed cycles were shorter (5-7 years), but the amplitude of growth was relatively
smaller during this period. The observed peculiarities in the ring width growth are identified for trees of different age groups (classes). The youngest trees stand out against the general background. They are characterized by the well expressed overall growth in 1960-1975 compared to the old and middle-aged groups of trees. The maximum amplitude of ring width growth was noted from 1920 to 1955. Until 1980, the rate of growth during different cycles was approximately the same as before 1910. Since 1980, there has been a general decrease in the ring width growth relative to the average value.

Figure 3. Average increment in the ring width of Norway spruce for three age classes [14].

Correlations have been calculated between the annual ring width increment of Norway spruce and air temperature or precipitation (calculations were performed using Statistica 6.0 data analysis program). Statistically significant results were established only for: a positive correlation with April and January temperatures, April and September precipitation values, and a negative correlation with February temperatures. These results are difficult to evaluate. This may be due to the use of data from the weather station (the Voeikov Main Geophysical Observatory, St. Petersburg), which is quite far from the study site.

It is preferable to use data from the Lyuban weather station located 25 km from Lisino in the same landscape conditions. However, only weather observation data starting from 1945 are available. To reconstruct chronological data on average annual air temperature and precipitation for an earlier period (1910-1945), we can use the observation data from the meteorological station of the Voeikov Main Geophysical Observatory [19]. A comparative analysis of observations from both weather stations for the period from 1945 to 2020 was carried out (figures 4-5).

Figure 4. Average yearly air temperature for the Lyuban weather station and the Voeikov Main Geophysical Observatory in St. Petersburg.
Figure 5. Precipitation by year for the Lyuban weather station and the Voeikov Main Geophysical Observatory.

The average yearly air temperature and annual precipitation at the Voeikov weather station are 1.38 °C and 13 mm higher than in Lyuban. The graphs with changes in the annual temperatures and precipitation for both stations are practically synchronous. This makes it possible to use data of the Voeikov Main Geophysical Observatory to reconstruct temperature and precipitation data for the period 1900-1945 at the Lyuban weather station with appropriate adjustments for the difference identified (figures 4-5).

4. Conclusion

Based on the dendrochronological studies in Lisino, it has been found that the radial growth of Scots pine and Norway spruce is a sensitive indicator of changes in the climate and water regime of soils. The degree of tree-ring width increment, other conditions being equal, depends on the age of trees. There is a well-established tendency demonstrating a decreasing growth rate of trees in the last decade of the XX century. The radial growth related to soil drainage is superimposed on the natural trend of tree ring width changes. This trend is characterized by fluctuations of different degree from the average growth value throughout the life cycle of trees. Such a trend of tree growth dynamics appears regardless of the soil type and physiological features of trees. It is related to temperature and precipitation fluctuations. The connection between the growth of ring width and climate is of a complex nature. It is caused by the fact that climate influences tree growth both directly (temperature) and indirectly, through soil regimes (water and heat). The anthropogenic impact on forest ecosystems also causes certain adjustments to the relationship between radial growth of trees and climate.

Analysis of growth dynamics in the tree ring growth charts allows distinguishing zones with trees where ring width increments are close to the average growth value, as well as zones with increased and decreased values of radial growth. The succession of zones reflects the cyclical pattern of ring width growth. An assessment of the effects of global climate change on the vegetation potential of soils and forest plantation productivity will not be accurate without a study of the causes and mechanisms of cyclical growth. Models of Scots pine and Norway spruce radial growth can be built on the basis of “plant-soil-climate triad” monitoring data.

Taking into account the availability of materials of dendrochronological studies of Scots pine and Norway spruce with precise spatial and temporal reference, it is advisable to organize monitoring of radial growth of trees in Lisino as an indicator of changes in climate and habitat conditions.

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