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LONG-TERM GROWTH TRENDS ANALYSIS OF NORWAY SPRUCE STANDS IN RELATION TO POSSIBLE CLIMATE CHANGE: CASE STUDY OF LENINGRAD REGION

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The Lisino training and experimental forest of the Saint-Petersburg State Forest Technical University was chosen as a study area. The forest is located in the central part of the Leningrad region and has a high level of protection as a forest of scientific and historical value. According to the official data, mean annual temperature in the region increased by 0.6 °C within 10 years as well as precipitation. The impact determination of changing climate conditions on Norway spruce trees growth was the aim of this study. Three most representative compartments dominated by Norway spruce (*Picea abies* (L.) Karst.) were selected for data collection. Core samples were taken by the Pressler increment borer from 107 dominant trees while climatic data were obtained from the nearest weather stations. Tree rings were measured and analyzed using WinDendro software while climate data were processed by Microsoft Excel. Tree ring data cover the time interval from 1848 to 2011, each ring was characterized by width, calendar year, age and diameter of the tree. Radial growth was analyzed within age and diameter classes. Annual rings widths were varied from 0.1 to 6 mm. There was a positive trend in age classes of 0-20, 21-40 and 41-60 years old. The growth was very slow in the age classes of 61-80, 81-100 and >100. Diameters are larger in the age classes of 20-40 and 41-60 as compare to the local diameter growth table which was developed in the 19th century. Diameters for age classes older than 41-60 years were less than prescribed by the diameter growth table. Annual rings width for all age classes also demonstrate cyclic dynamics, moreover, the decline in growth sometimes occurred in recent decades. Multiple regression was used for developing the response function of growth to changes in climatic conditions. There was revealed a high correlation (90 %) and low influence of vegetation period climate data on growth during 1848–2011 (0.08102 mm/°C and 0.00085 mm/mm). Likewise, analysis shows that growth is higher in young and middle-aged than mature and over mature stands. Overall, climate change impact has a positive effect on the radial growth of Norway spruce for the studied area, however, not for all age and diameter classes.
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Keywords: Norway spruce, annual ring width, climate change, age classes, growth trend, temperature, precipitations.

Introduction

Official data shows the reliable temperature growth in the last decades, especially for northernmost areas, for instance in the taiga region. In taiga, temperature is one of the most important ecological factors limiting forest trees' growth and development. Changes in mean and seasonal temperatures in spatial aspects for the Russian Federation are presented in Fig. 1.

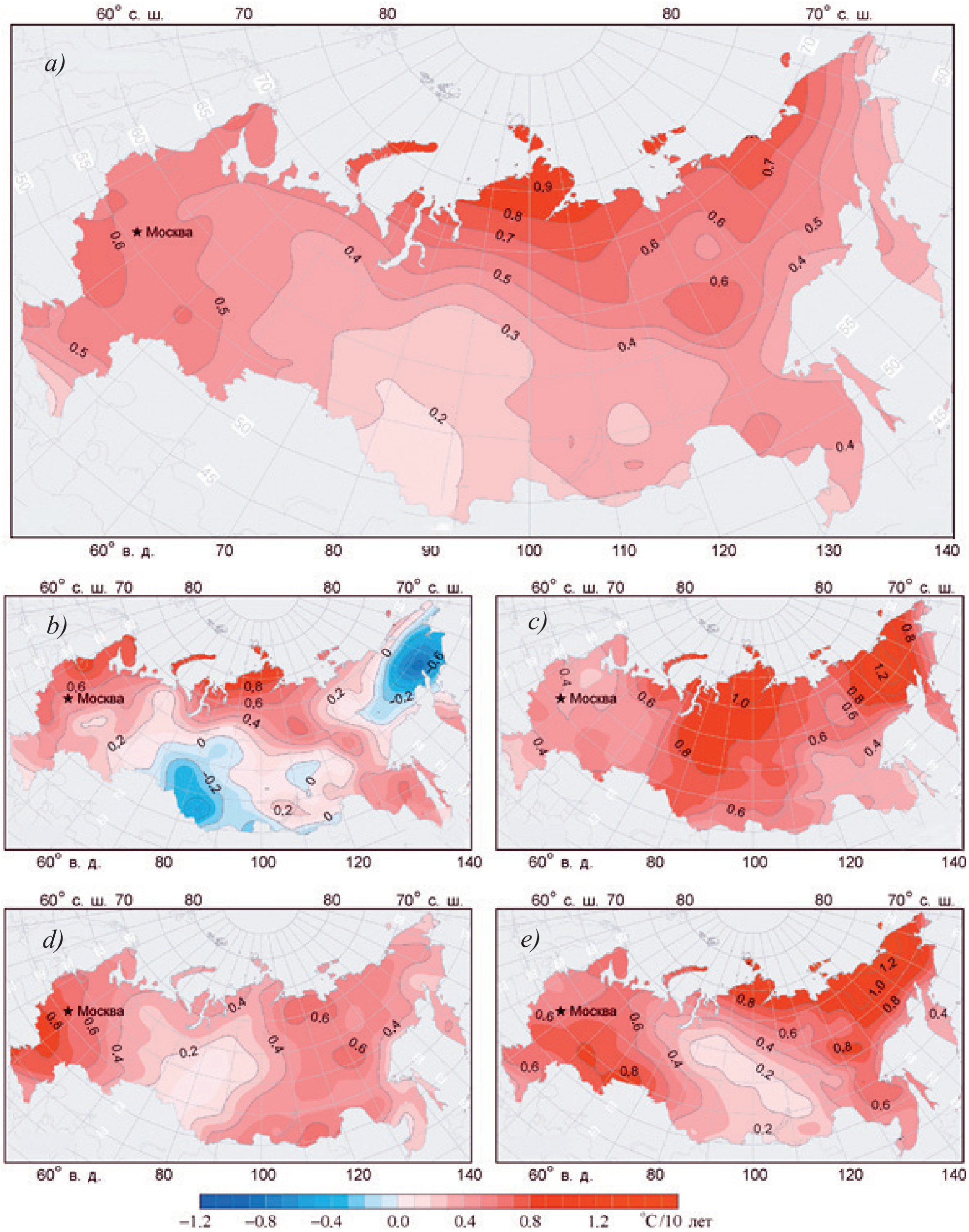

Fig. 1. Spatial pattern of mean temperature variation in Russia: *a)* – annual; *b)* – winter; *c)* – summer; *d)* – spring; *e)* – autumn. Adopted from [4]

Leningrad region belongs to the area with an increase in mean annual temperature. Area, where study plots are located, belongs to the territories with temperature increase by 0.6 °C within 10 years. Changes in annual precipitation over the last 75 years and its deviations for the Russian Federation are presented in Fig. 2. Dots on the maps represent locations of the weather stations.

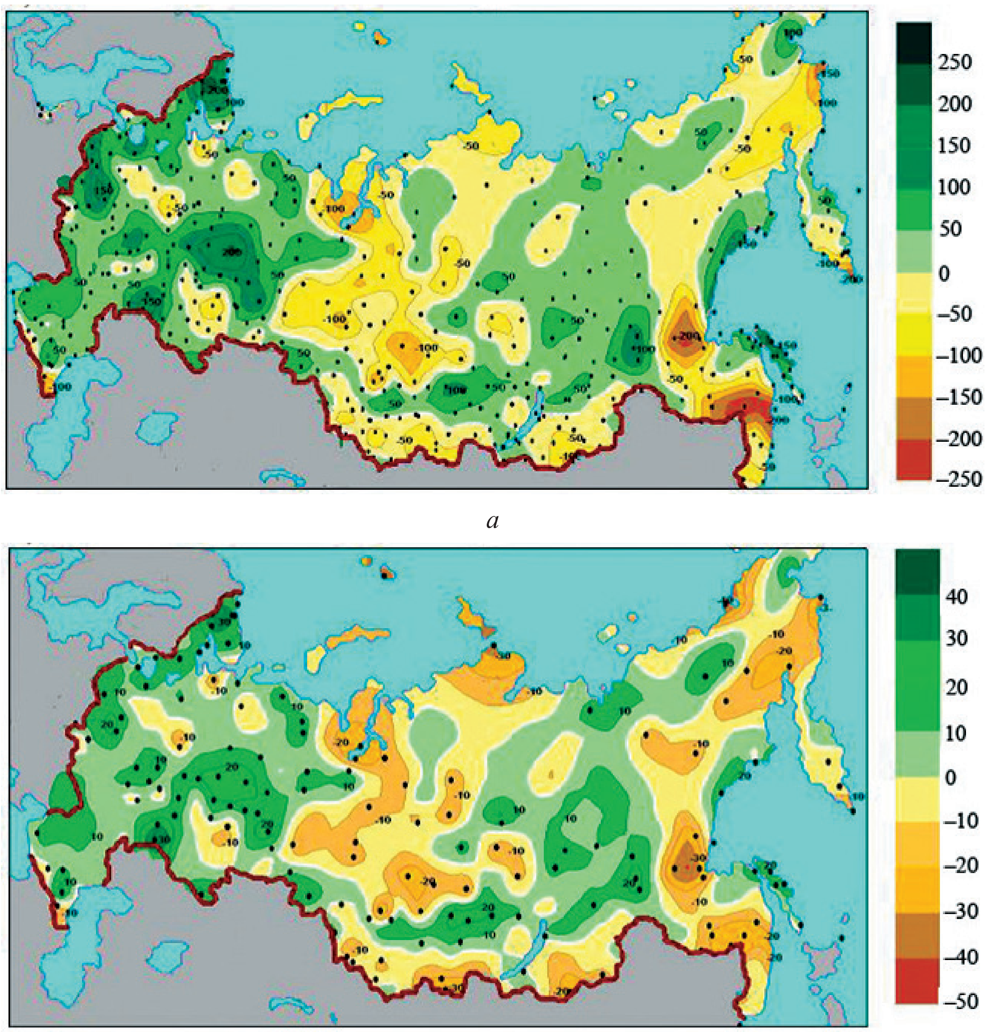

Fig. 2. Spatial pattern of annual precipitation changes during 1936–2010 in Russia: *a* – over the last 75 years, mm; *b* – % of the mean value in 1961–1990. Adopted from [4]

In Leningrad Region, there is no or only minimal changes in annual precipitation, measured both in mm and as a percentage of normal precipitation in 75 years.

The estimation of impacts of changing climate conditions on Norway spruce trees growth was the aim of this study. Leningrad region belongs to the areas with an increase of mean annual temperature that is why it is a reason to suppose here elevated growth in radial increment of main tree species as a reaction to climate warming. Increased plant growth in the northern latitudes is an expected outcome of recent climate changes towards warming [19], also such a trend was established for the large areas of European forests [8, 21, 22].

The research area in the narrow sense was Lisino training and experimental forest of the Saint-Petersburg State Forest Technical University. It belongs to the taiga zone, located out of the influence of damaging factors, has a high-level protection status. This is a forest of high scientific and historical value because it was founded in 1805 and since this time continuously used for research and training. It may be considered as a proper place to boost forest growth registration due to climate warming.

Dendrochronology approach to Norway spruce tree stands radial increment analysis was used as the main method for growth trends revealing. This approach for a long time widely and successfully implemented for the study of climatic impacts on trees growth analysis [3, 5, 10–15, 23, 25], as well as for other environmental factors, which may influence forest growth assessments [16, 17, 20, 24].

Materials and methods

The study area location of the Lisino training and experimental forest of the Saint-Petersburg State Forest Technical University is shown in Fig. 3.

Fig. 3. Location of the study area on the maps of Russia and Leningrad region

The study area is situated on Ladoga-Ilmen lake-glacial lowland (the bottom of lake-glacial basin) from the geomorphologic point of view. The height above sea level varies from 20 up to 70 m. The largest river Lustovka crosses the forest from NW to SE. There are three streams in the forest area: Laguza, Heart and Kastenka. In addition, two channels Kuznetsovskiy and Kozhinskiy pass through the forest. All of these operate as a drainage system for the lowland forested area. The topography is flat and undulating. Small flat hills formed by glacial debris are scattered throughout the forest. Podzol formed in a marsh is the main soil type in Lisino. Other predominant soil types are moor-humus podsolization (20 %), podzolic moder-mor humus (18 %), marsh soil (57 %), torf-podzolic (2 %) and alluvial soils (3 %). The soil is slightly acidic poor with well-developed podzolic humus horizons.

The climate is characterized as moderate and influenced by cold air masses coming from the Arctic, and the warmer air mass from the Atlantic. The regional climate is strongly influenced by the proximity of the Baltic Sea and Ladoga Lake.

According to the nearest weather station Luban, the maximum temperature in Lisino is 33 °C in July and the minimum is –40 °C in January. The average annual rainfall is approximately 590 mm. Additionally, the average wind speed is 3.3 m/s and average relative humidity is 80 %. The climatic conditions are favorable for the growth and development of trees and shrubs. The length of the growing period is approximately 150–160 days.

Norway spruce is the main species for the Lisino training and experimental forest. It occupies 34.5 % of the total area covered by forest. The second species is Scots pine, which takes 28.1 % of the area covered by forest.

Description of Norway spruce dominated tree stands where wood samples were collected is presented in Table 1.

Table 1

Characteristics of sampled Norway spruce stands

Species composition	Age, yrs	Height, m	Diameter, cm	Growing stock, m^3
Block – 123, compartment – 18, area – 3.1 ha				
Norway spruce, 50 %	130	28	32	470
Norway spruce, 30 %	90	24	24	280
Birch, 20 %	90	23	24	190
Scots pine, single trees	130	–	–	–
Aspen, single trees	90	–	–	–
Block – 200, compartment – 28, area – 2.8 ha				
Norway spruce, 80 %	130	22	24	550
Birch, 20 %	120	24	28	140
Scots pine, single trees	130	–	–	–
Block – 206, compartment – 5, area – 5.9 ha				
Norway spruce, 30 %	170	29	32	570
Norway spruce, 20 %	80	21	24	370
Scots pine, 30 %	170	28	40	560
Birch, 20 %	130	27	30	370
Aspen, single trees	130	–	–	–

As shown in Table 1 sampled Norway spruce dominated tree stands are old-growth of 80–170 years old on average, highly productive and with a mixture of Scots pine, birch, and aspen.

The Pressler increment borer tool was used to extract tree cores in all 3 compartments. One core per tree was collected from 107 sample trees of different ages. The samples were taken at the height of 1.30 m above ground level. The trees were selected in such a way which represented dominant trees (high trees which were free from disease and malformations) and the most vital trees in different age classes (ocular estimate) from all selected compartments. The oldest tree was 163 years old and the youngest tree was 30 years old in the sample, so annual ring data is available for the period 1848–2011.

The image analysis program WinDendro was applied to detect annual and intra-annual ring boundaries on the base of changes in light intensity of an image and requires manual adjustment to ring boundaries to account for growth anomalies (WinDendro, 2009). The ScannerCal calibration file allows WinDendro to compensate for differences in the dpi reported by the scanner and the real dpi measured with a high precision calibration target. Earlywood and latewood widths, as well as total ring width, were measured automatically for each annual ring sample. If there were almost no contrasts between rings for single-core samples the ring widths were measured manually. In the following analysis total annual ring width was used. Data on temperature and precipitation were collected on local weather stations for each year of the vegetation season of the whole growth period 1848–2011.

For the obtained annual rings data analysis was used before developed special method aimed on removing of age trend from annual ring width data [1, 6, 7].

Each tree ring with the following data was used as a basic unit for the analysis: annual ring width, calendar year of appearance, age of the tree in which the annual ring appears, the diameter of the tree in which the annual ring appears.

Then the annual ring data was grouped firstly by age class for comparison of annual ring width of trees of the same age growing in different calendar years and secondly by age class and diameter for diameter growth curve development for comparison with the data of regional growth and yield tables.

In order to determine the response function of radial increment on climatic factors, temperature and precipitation multiple regression analysis were used. The mean annual radial increment was related to mean temperature and precipitation for vegetation season:

$$y = a_1 x_1 + a_2 x_2 , \quad (1)$$

where y – mean annual radial increment of Norway spruce trees, mm; a_1 – regression coefficient, which reflects the effect on the radial increment of changes in temperature, mm/°C; x_1 – mean temperature of vegetation season for each year, °C; a_2 – regression coefficient, which reflects the effect on the radial increment of changes in precipitation, mm/mm; x_2 – mean precipitation of vegetation season for each year, mm.

The temperature dependence coefficient of Norway spruce trees for each age class was developed to assess the difference in reaction trees of different age on changes in temperature:

$$y_i = a_i x , \quad (2)$$

where y_i – mean annual radial increment of Norway spruce trees of age class i, considered age classes of 0-20, 21-40, 41-60, 61-80, 81-100, and >100 years old; x – mean temperature of vegetation season for each year, °C.

Regression analysis was done using STATISTICA 10.0 software.

Results and discussion

The long-term trends in Norway spruce radial increment are presented in Fig. 4.

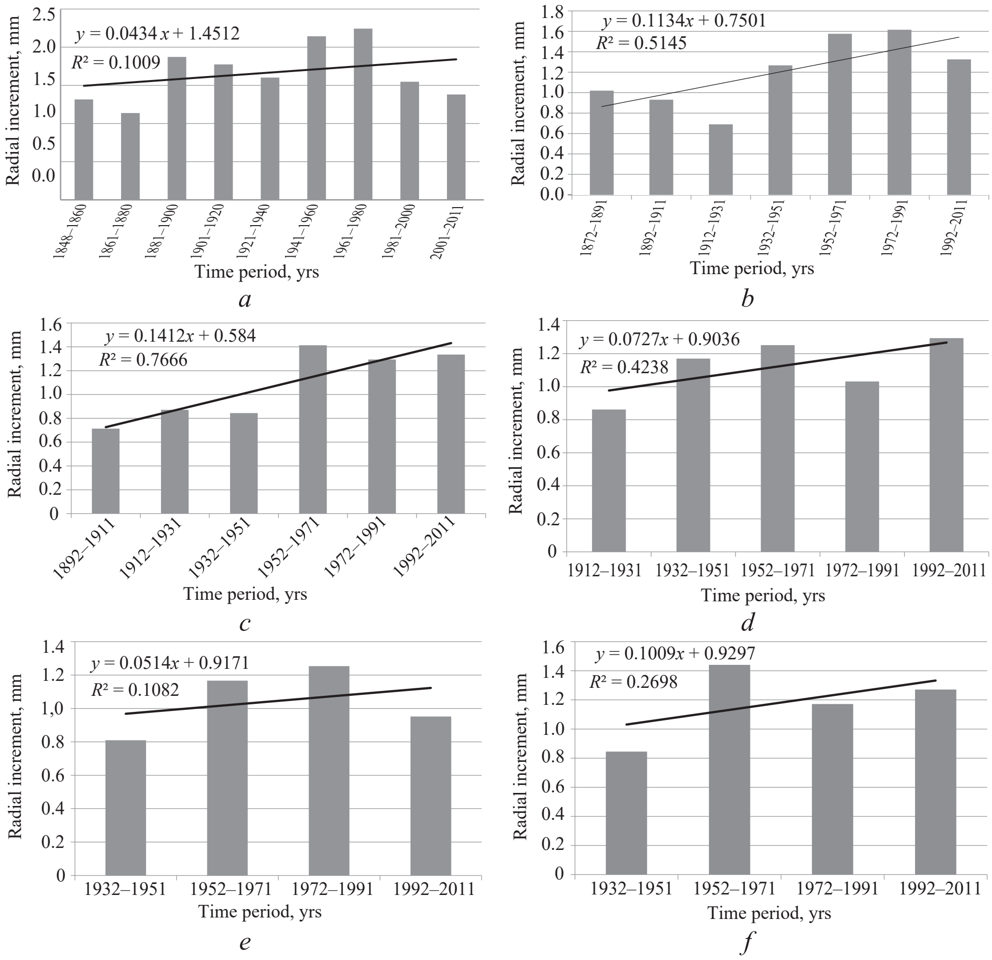

Fig. 4. The long-term trends in Norway spruce radial increment of different age class per 20-years intervals: *a)* 0-20; *b)* 21-40; *c)* 41-60; *d)* 61-80; *e)* 81-100; *f)* >100 years old

Fig. 4 shows the usual pattern between radial increment and age: the greater the age the smaller the increment. Also, as it may be seen from Fig. 4, only for age classes 21-40 and 41-60 there is a statistically reliable trend in the radial increment of Norway spruce trees. For all age classes, including 21-40 and 41-60, increment for the last period is less or almost the same as for some previous ones. For example, for the youngest age class 0-21, the increment for the last period is less than in 6 previous 20-years intervals and the same as in 1848–1860. In addition, the increment dynamics show cyclical changes with a period of approximately 80 years. So, the comparison of Norway spruce radial increment of the same age class growing in different calendar years gives no clear evidence of elevation of increment for the last years as it is supposed to be due to the registered climate warming in the last decades and according to research hypotheses.

Radial increment response function on temperature and precipitation was obtained as a result of two-factor regression analysis. Regression function with coefficients a_1 = 0.08102 mm/°C and a_2 = 0.00085 mm of increment/mm of precipitation, which explains mean annual radial increment with determination coefficient of 81.5 %, was developed. Analysis shows practical independence of radial increment on precipitation during vegetation period because coefficient a_2 is very small and weakly dependent on mean temperature of vegetation season. The fact of radial increment independence from precipitation of the vegetation season may be easily explained by the traditional excess of precipitation during evaporation for the studied area, the absence of significant changes in precipitation (see Fig. 2), concave landforms and prevailing of wet soils. The temperature dependence coefficient of Norway spruce radial increment for each age class is presented in Table 2.

Table 2

Temperature dependence coefficient of Norway spruce trees radial increment

Age class, yrs	Coefficient increment – temperature, mm/°C	Determination coefficient, %
0-20	0.123	88
21-40	0.085	90
41-60	0.075	89
61-80	0.074	92
81-100	0.071	86
>100	0.069	96
Mean	0.08283	90

The Norway spruce radial increment of any age class statistically reliable depends on mean vegetation season temperature as it is shown by the data from Table 2, the younger trees the stronger reaction on warming during vegetation season, the coefficient for age class 0-20 years old is approximately as much as twice more than for the age class older than 100 years. The mean temperature dependence coefficient is approximately the same as a1 and demonstrates also slow mean reaction of increment on temperature changes. If take the temperature growth of 0.6 °C within 10 years for the research area as it officially estimated [4] or 0.06 °C per year the increment reaction will be as much as $0.06 \cdot 0.08102 = 0.0049$ mm and cannot be reliably registered.

Dendrochronological data after special treatment offer a possibility to develop the diameter growth curve for Norway spruce stands and it is of interest to compare the result with diameter growth for the same area but which took place in the previous century. For comparison of diameter growth nowadays and before the local growth and yield tables developed by Vargas de Bedemar in the 19th century for the Lisino training and experimental forest of the Saint-Petersburg State Forest Technical University was taken. The comparison results are presented in Fig. 5. As seen in Fig. 5 only for two age classes of 21-40 and 41-60 years old mean diameter of Norway spruce stands exceeded data of growth and yield tables meanwhile for all others age classes diameter growth is the same or even less. So, the comparison of diameter growth curves derived from radial increment data and growth and yield table of the 19th century doesn't provide clear evidence of Norway spruce stands elevated growth for the last decades.

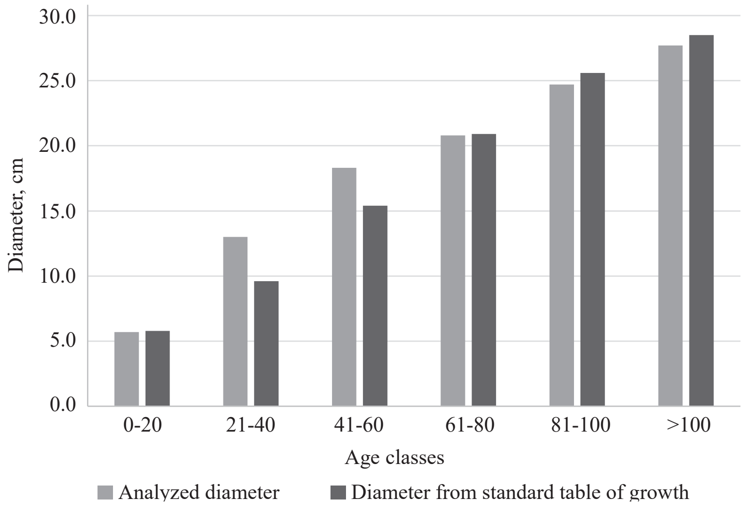

Fig. 5. Mean diameter growth of Norway spruce stands in comparison with the data of regional growth and yield tables

Conclusion

There is a reliable official data on some increase of mean temperature per year as well as for vegetation season for the study area which belongs ecologically and geographically to the south taiga climate zone. It is well known that temperature is one of the main ecological factors limiting the Norway spruce trees growing in the taiga zone. It has shown by the calculated temperature dependence coefficient describing the relationship radial increment/mean temperature for the vegetation season. The increase of mean vegetation season temperature in the last decades should stimulate Norway spruce trees growth but this is not the case of our study. The analysis showed that slowly increased long-term growth of trees of all age classes is statistically reliable only for age classes of 21-60 years old. At the same time for the last 20 years a decline in the radial increment of trees of 0-20, 21-40 and 81-100 years old was revealed; meanwhile, for trees of 41-60, 61-80 and >100 years old radial increment was the same or less than in some previous period. Comparison of experimental and taken from growth and yield table Norway spruce stands diameter growth curves also do not indicate elevated diameter growth for the last decades.

Generally, the absence of elevated growth for the last 20 years and even its decline may be probably explained by growth cycling dynamics with the cycle of approximately 80 years as presented in Fig. 4. During the last decades climate warming does not affect Norway spruce stands growth as it has waited. Two reasons may be considered as explanations of such a fact. First, climate warming is still insignificant yet for the study area and has not led to a definite radial increment increase of Norway spruce trees of all age classes. Second, no clear influence of climate warming on Norway spruce trees growth may be explained by optimality of study area climate conditions. According to Shelford’s law of tolerance (Fig. 6) if the temperature belongs to the optimal zone it rising may cause both increase and decline in growth [9].

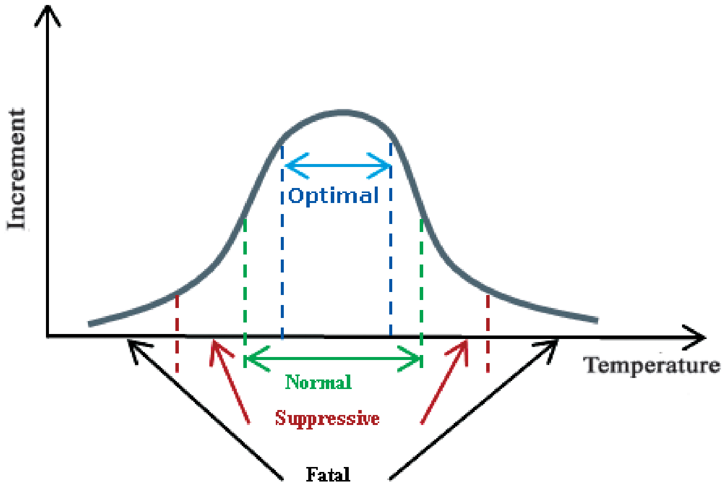

Fig. 6. Shelford’s law of tolerance. Horizontal axis includes temperature diapasons as these effects on radial increment (fatal – no increment; suppressive – low increment; normal – satisfactory increment; optimal – maximum increment with both increase and decrease of the increment)

Almost the same results were obtained for the mountainous regions of Northern Italy when the influence of climatic factors on the growth of Norway spruce (*Picea abies* (L.) Karst.) and European pine (*Pinus cembra* Pall.) was studied [2]. Similarly, it was found that the radial increment is weakly responsive to changes in climatic factors due to close to the optimal temperature and moisture growth conditions. It is possible to mention here one interesting analysis as a result of which there is no direct influence of temperature on the productivity of plants growing in low or high-temperature environments [18]. The mean productivity of natural vegetation appears to be the same per time unit of the vegetation season in the tropical and near Polar regions despite big temperature differences. The total productivity of plants in these cases is determined by the duration of the growing season if all other environmental factors are at a satisfactory level.

As a general conclusion, we may say that the research on relationships of Norway spruce stands growth and variation of climate conditions should be continued.

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АНАЛИЗ ДОЛГОВРЕМЕННЫХ ТЕНДЕНЦИЙ РОСТА ДРЕВОСТОЕВ ЕЛИ ЕВРОПЕЙСКОЙ В СВЯЗИ С ВОЗМОЖНЫМ ИЗМЕНЕНИЕМ КЛИМАТА (НА ПРИМЕРЕ ЛЕНИНГРАДСКОЙ ОБЛАСТИ)

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Долговременные тенденции роста древостоев ели европейской изучались на территории Лисинской части учебно-опытного лесничества Ленинградской области, расположенной в ее центре и имеющей высокий защитный статус ценных лесов, имеющих научное и историческое значение. По официальным данным среднегодовая температура в районе исследований возросла на 0,6 °С за 10 лет, среднегодовые осадки также увеличились незначительно. Цель исследований – определение влияния произошедших изменений климатических показателей на рост деревьев ели европейской (*Picea abies* (L.) Karst.). Три наиболее типичных выдела с преобладанием ели европейской были выбраны для сбора данных о ходе роста древостоев. Образцы древесины отобраны буравом Пресслера у 107 деревьев, метеорологические данные получены по наблюдениям ближайшей метеорологической станции. Радиальный прирост измерен с помощью

калиброванного сканера и специализированной программы WinDendro, полученные результаты совместно с метеорологическими данными обработаны в программе Excel. Данные о радиальном приросте модельных деревьев покрывают интервал с 1848 по 2011 г., каждый годичный слой характеризовался календарным годом образования, шириной, возрастом и диаметром дерева. Радиальный прирост деревьев анализировался по классам возраста и ступеням толщины. Ширина годичных колец варьировала от 0,1 до 6 мм. Выявлены положительные тренды радиального прироста для классов возраста 0-20, 21-40 и 41-60 лет. Для классов возраста 61-80, 81-100 и более 100 лет положительные изменения радиального прироста оказались недостоверны. Анализ хода роста деревьев по диаметру путем сравнения с местными таблицами хода роста показал больший диаметр для классов возраста 21-40 и 41-60 лет, для остальных классов возраста он оказался меньше указанного в таблицах. Радиальный прирост для всех классов возраста продемонстрировал наличие циклической динамики изменений, причем падение прироста иногда приходилось на последние десятилетия. Для построения функции отклика прироста на изменение климатических условий был использован множественный регрессионный анализ. С высокой степенью достоверности (90 %) установлено слабое влияние температуры и количества осадков за вегетационный сезон на радиальный прирост деревьев с 1848 по 2011 г. (0,08102 мм/°С и 0,00085 мм/мм). Кроме того, анализ показал более сильную реакцию радиального прироста на изменения климатических условий у молодых и средневозрастных древостоев по сравнению со спелыми и перестойными. В целом изменения климатических условий имеют положительное влияние на радиальный прирост, но не для всех классов возраста и ступеней толщины.
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Ключевые слова: ель европейская, ширина годичных колец, изменение климата, класс возраста, тренд радиального прироста, температура, осадки.

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