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Dendroclimatic diagnostics of pine and spruce growth in the Kivach Reserve (Russian Karelia)

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ABSTRACT

The results of the correlation analysis of Norway spruce and Scots pine growth at the conditions of the Kivach Reserve are discussed in the article. High summer temperatures of the previous season have negative effect on Norway spruce radial growth. High amounts of February precipitation are negative for spruce growth too. The effect of climatic impact on pine radial growth is different for different sites. A positive reaction for the above-mentioned average amounts of June precipitation is a specific feature of chronologies from dry growing sites of pine trees. A significant positive correlation with February precipitation is typical for chronologies from semi-wet sites. Chronologies from bogs (except bogs from lakesides) negatively correlate with November precipitation of the previous calendar year. The negative effect of high December temperatures is significant for most sample areas from different pine growing sites.

Key words : *Norway spruce, Scots pine, Karelia, Radial growth, Tree rings, Dendrochronology, Dendroclimatology*

Introduction

Knowing the mechanisms of tree growth is of an essential importance for silvics and silviculture. A dendroclimatic method – the study of tree ring variability caused by changes in weather patterns – offers great opportunities for further studies in this field. Traditionally, dendroclimatic researches target woodlands under extreme growth conditions, such as forest-tundra ecosystems (Lovelius, 1979; Shiyatov, 1986; Vaganov *et al.,* 1996; Mazepa, 1998). The main research objective here is to use indicative potential of trees and to reconstruct past weather conditions based on the obtained chronologies.

Patterns of climate-based growth variability in conifer species provide valuable data for silvicultural purposes in intensive forestry arears (Bitvinskas, 1974; Molchanov, 1976; Tarankov, 1996; Feklistov *et al.,* 1997). In this respect, it is of key importance to study intrapopulation polymorphism through climate-based growth variability (Bitvinskas, 1974). The Kivach Reserve lies in the industrial region of the country with intensive forest use, which contributes to a higher demand for intensification of forest management. This will be possible if we have deeper knowledge of ecological growth patterns in conifer species in this region.

Protected natural areas are the most suitable sites for studying natural ecological growth patterns because anthropogenic factors have a lower impact on growth processes here (industrial activities, recreation, industrial pollution) (Vaganov *et al.,* 1996).

The Kivach Reserve is one of the oldest natural reserves in Russia (founded in 1931) that shows a great variety of landscapes within quite a limited area and a wide phenotypic diversity of spruce population. A.P. Kutenkov, a veteran member of the Kivach Reserve, defines its wildlife diversity as *"a*

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*Professor

unique combination of typical features" (Kutenkov, 2000): "*within the Reserve stretching for 12km at most from the north to the south and for 14rm from the west to the east we will not see anything that could not be found anywhere else (again, apart from the second highest waterfall in the European flat lands). On the contrary, geological elements, landscape forms, water bodies and bogs, flora and fauna are typical either for the whole European taiga or at least for European Fennoscandia. However, if the destiny had other plans for this area and the polygon of the Reserve happened to lie on any side from its existing borders, we would see a picture much poorer in palette, plot and contents.*" Thus, the Kivach Reserve seems to be the most suitable site for dendroclimatic research of growth ecology of conifer species in Southern Karelia, which may give grounds for sufficiently wide generalizations.

Materials and Methods

Field studies were performed in the Kivach Reserve for four seasons from 2000 to 2003. Pine growth was studied in terms of typological forest diversity, and spruce growth was studied predominantly in terms of diversity by the shape of a seed scale. P.P. Popov's method (1999) was used to classify spruce trees by the shape of a seed scale.

An increment borer was used to extract core samples at a height of 1.3 m with a spot on the stem being chosen at random. One core sample was extracted from each tree under study. Tree ring width was measured using a MEC-10 microscope to a precision of 0.05 mm at least. Cross-dating was done using a GROWLINE software package designed by the Department of Forest Management, Ecology and Forest Protection of Moscow State Forest University (Lipatkin and Mazitov, 1997). A graphical and statistical analysis of the data obtained was done using Microsoft Excel spreadsheets and STATISTICA 6.0 software.

This research contains the meteorological measurements taken by the Kivach's weather station from 1966 – 2002. A climatic component of annual radial growth variability was identified through calculations of growth indexes. These indexes were calculated as a ratio of a tree ring width observed this year to the mean tree ring width observed for the last five years. The chosen indexing method ensures nonspecific elimination of the effects caused by long-term factors of various natures (Fritts, 1976).

Generalized chronologies for tree groups were calculated based on the individual chronologies obtained. Growth index correlation coefficients were calculated for meteorological parameters of the year when the growth was achieved and for meteorological parameters of the preceding year. With the number of degrees of freedom = 30 and the significance level = 0.05, correlation coefficients higher than 0.35 can be considered as reliable (Lakin, 1973).

Results

Spruce growth. In the course of the research, we obtained a spruce chronology related to the trees belonging to all growth classes (a number of trees under study is given hereinafter in brackets – 99); a chronology related to the trees of the dominant growth class (general chronology) (107); a chronology for Norway spruce (*Picea abies*) and for Fenns spruce (*Picea fennica*) (43). All chronologies were obtained for the prevailing green moss type of forests. A chronology was also established for spruce trees from a bog moss pine forest under high bogging conditions (10) and for spruce trees growing in a sparse stand by a spring-water source (the Source Hill) (13).

Within the general chronology taken for the period from 1967 to 2000, the reliable correlation is observed for temperature in June (correlation coefficient (r) = -0.69), July (r = -0.54)and August (r = -0.54) of the last year. Correlation to precipitation is reliable for February of the current year (r = -0.51). Figure 1 shows the results of the correlation analysis.

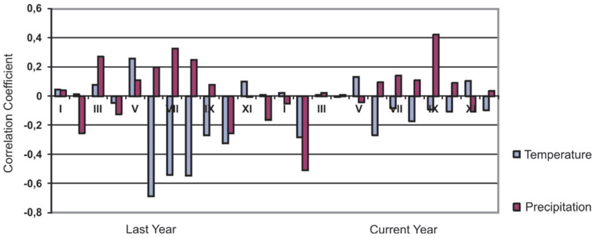

Fig. 1. Impact of weather conditions in various months on Spruce growth in green bog spruce forests

In general, all chronologies show a similar response to the impact of climatic factors.

Besides, the spruce tree growing on the Source Hill shows a positive reaction to temperatures observed in May of the current year (r=0.40), and a negative reaction to temperatures observed in June of the current year. It also differs from the main chronology in the growth reaction to high temperatures of the last year (there is a reliable negative reaction to June temperatures (r = - 0.41) and to August temperatures (r = – 0.52)).

The spruce from the bog moss pine forest shows a slightly lower responsivity to February precipitation (r = -0.39). Its growth correlates to temperatures of the last summer as follows: (June: r = -0.66; July: r = – 0.57; August: r = – 0.34).

It is essential that chronologies related to Norway spruce (*Picea abies*) and Fenns spruce (*Picea fennica*) do not differ in their reaction to climatic factors though some authors reported on a different sensitivity of these intraspecific forms to the influence of climatic factors (Panin, 1957; Moskvitin, 1959; Milyutin, 1963; Scherbakov, 1984; Iliinov, 1998).

The relation between a growth index and meteorological factors was simulated by a multiple linear regression equation. For this purpose, we used a chronology related to spruce trees of the dominant growth classes. The resulting equation is characterized by the coefficient of determination R^2=70% and the model confidence level of 95%. The equation is as follows:

$$Y = 2.22 - 0.00226 \times O_2 - 0.02612 \times T_6 - 0.0241 \times T_7 - 0.03117 \times T_8$$

where **Y** is a growth index;
O_2 is total precipitation in February, mm;
T_6 is temperature in June last year, °C
T_7 is temperature in July last year; °C
T_8 is temperature in August last year, °C.

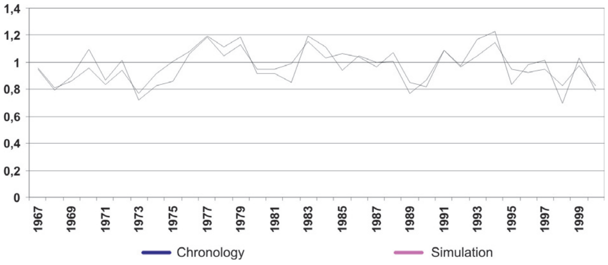

Fig. 2. Results of the growth index simulation based on the linear regression equation

Simulation results are presented in Figure 2.

The equation above makes it possible to predict a tree ring width before growth formation begins. To convert indexes to absolute values it is necessary to multiply the estimated index value by an empirical mean value that will be different for trees of different age, different sociological positions, and different orographic positions (for example, trees growing at the esker foot have a higher growth rate because of eluvial enrichment of the soil). Among all independent variables, the highest contribution to growth variability belongs to June temperature (48%) and August temperature (14%); the impact of July temperature (4%) and February precipitation (4%) is insignificant.

Pine Growth : Pine trees were selected from growing sites of three types: dry sites (lichen pine forests on the eskers), semi-wet sites (pine forests of a Myrtillus type and Vaccinium type growing in sandy loam) and wet sites (bog moss pine forests, pine forests of a Ledum type and Cassandra type). Five sample areas were arranged for each type of growing sites (TGS). Each of these sample areas was characterized by a generalized chronology related to 12 trees under study. There were specific climatic factors typical of the studied groups of pine forests that influenced growth as represented by the correlation analysis results (Table). When analyzing the primary correlation matrix we took into consideration both reliability of the correlation coefficient values (r) and their repeatability for chronologies within TGS. The analysis results are summarized in the Table.

It was established that pine growth in dry TGS largely depended on the total precipitation in June of the current year (r=0.38…0.43). In semi-wet TGS, growth can be positively influenced by precipitation in February (r= 0.28…0.32). In wet TGS (high bogging), we observed a negative relation to precipitation in November (r=-0,44…-0.51). However, this relation was not observed in swampy pine forests on the shore of the lake.

We observed a negative relation between pine growth and temperature in December preceding the vegetation period (Table) for all TGS in most sample areas. This relation is graphically represented in Figure 3. It shows a conjugated variation of the pine growth index and the December temperature index over 33 years. The latter is a ratio of temperature in December of the current year to long-term average temperature of this month. Maximum values of the December temperature index correspond to the coldest period as shown in Figure 3. High monthly temperatures negatively affect pine growth.

The relation is not equally well evident in various parts of the time series. However, a closer relation to December temperature can hardly be expected. It is

Table. Coefficients of correlation between growth indexes and climatic factors

Chronology based on TGS	December Temperature, °C	June Precipitation, mm	February Precipitation, mm	November Precipitation mm
Dry 1	-0.21	0.39	0.07	-0.22
Dry 2	-0.47	0.40	0.20	-0.21
Dry 3	-0.44	0.38	-0.02	-0.41
Dry 4	-0.31	0.49	-0.07	-0.18
Dry 5	-0.34	0.43	-0.11	-0.35
Semi-wet 1	-0.44	-0.01	0.28	-0.36
Semi-wet 2	-0.28	-0.13	0.31	-0.16
Semi-wet 3	-0.13	-0.14	0.32	-0.20
Semi-wet 4	-0.49	0.02	0.31	-0.16
Semi-wet 5	-0.41	-0.04	0.28	-0.26
Wet 1	-0.54	0.09	-0.01	-0.44
Wet 2	-0.53	0.17	0.00	-0.46
Wet 3	-0.40	-0.10	0.00	-0.51
Wet 4	-0.53	0.13	0.24	-0.19
Wet 5	0.07	0.12	-0.21	0.00

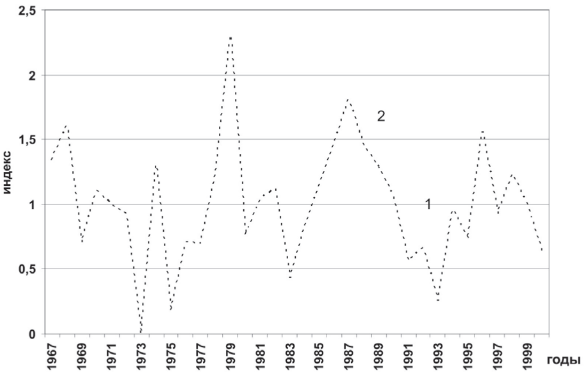

Fig. 3. Conjugated dynamics of pine growth indexes (1) and temperature in December (2) preceding to the vegetation season.

obvious that average monthly temperature in December is not a factor that influences growth (unlike precipitation in June of the current year), but just an index correlated to this factor. The use of time series related to other characteristics of December temperature patterns (maximum temperature, minimal temperature, mean maximum temperature and mean minimal temperature) did not reveal any closer relation between growth and weather conditions of this month.

The regression analysis showed that the abovementioned factor explained up to 30% of growth index variability for the generalized chronologies based on types of growing sites; the multiple correlation coefficient was 0.56 for the chronology for dry pine forests and 0.51 for the chronology for semi-wet pine forests.

Discussion

Impact of weather in summer months – In South Karelia, June is a period of the most intense growth processes (Kischenko, 2000; Chernobrovkina, 2001). June precipitation is a specific factor that forms growth in pine trees from forests growing on rocks. This type of pine forests appears on top of the eskers where a thin underlay, a waterproof crystalline bottom part, and a broken ground ensure an intense rainwater runoff, which results in highly limited water storage. The low-density tree stand formed under these conditions lets a lot of light through forest canopy, which ensures heating and drying up of a relatively thin soil layer. Atmospheric precipitation that occurs within the period of intense growth formation positively influences its rate. In a similar manner, a significant correlation was observed between pine growth and total precipitation in June in central Norway in soils with low moisture capacity (Slastad, 1957 according to Makinen *et al.*, 2000).

High temperature in June of the last year is the most significant factor that negatively affects spruce growth. As noted by N.P. Chernobrovkina (2001), days when air humidity goes down to 25-35% are not rare in May and June in South Karelia. Thus, a short-term drought occurs and negatively affects plant growth and development, which is particularly bad for the health of the most active roots found in the upper drying-up soil horizon. We can conclude that the negative impact of high temperatures observed in June and other summer months on spruce growth is caused by the integrated effects of water stress that can involve both soil and air drought.

It has been reported many times that there is a delay in a response to water stress in Norway spruce growth. According to Hettonen (1984), temperatures of the second half of the preceding summer negatively influence spruce growth. As noted by the author, the same negative effect of the warm preceding summer has been reported for spruce growth by other researchers (Wallen, 1917; Eklund, 1957; Jonsson, 1969; Feliksik, 1977; Elkstein, Anial, 1981).

A detailed analysis of spruce variability along the geographic gradient has been recently performed in Finland (Makinen *et al.*, 2000). As a result, the authors obtained chronologies related to five areas from central Finland up to the arctic boundaries of spruce forests. The cross-correlation analysis showed that growth variations contained in the chronologies were closely associated with summer temperatures in the year of growth formation. A positive influence of high average June temperatures was the most apparent. The degree of association between radial growth and June temperatures increased from the south to the north. A negative correlation was also observed between growth indexes and high temperatures in February. However, there was also a significant negative correlation to temperatures of the preceding summer with the correlation degree going down as we moved to the north.

A number of Russian authors reported that droughts of the preceding year had a negative influence on spruce growth in southern taiga (Rostovtsev, 1962; Bugaev and Lozovoy, 1978; Matusevich and Maslov, 1982; Buyak and Karpov, 1983; Melnik, 1996).

The phenomenon of a delay in a spruce growth reaction to droughts has a number of curious features. Thus, a chronology may contain a positive response to high temperatures in June of the current year and a negative one to high temperatures in June of the preceding year (Makinen *et al.,* 2000). While having a negative reaction to both insufficient and excessive moistening, spruce growth decreases in the very year of excessive moistening and only in the following year after insufficient moistening (Buyak and Karpov, 1983). There is an integrated model of tree-ring width reduction under the impact of water stress occurred in the preceding year (Fritts, 1976). Our results can be explained in the context of this model.

Impact of December temperatures – We observed a negative relation between pine growth and temperature in December preceding the vegetation period for all TGS in most sample areas. There are the similar data obtained for the central part of the Kola Peninsula, where high February temperatures had a negative influence on pine growth (Raspopov *et al.,* 2002).

The negative impact of high December temperatures on pine growth is apparently explained by frost injuries in pine trees when their dormant state is disturbed. There has been much discussion of frost injuries in Scots pine with rising winter temperatures in Fennoscandia (Hanninen *et al.*, 1993; Hanninen *et al.,* 1996; Junttila, 1996; Leinonen *et al.,* 1996).

Impact of November precipitation – In wet TGS (in a situation of high bogging), the negative impact of November precipitation on pine growth could be explained as follows. Water table depression has a positive influence on growth in wet pine forests thanks to better soil aeration and to a variety of positive effects associated with this process such as better aerobic respiration of roots, lower formation of toxic iron protoxide compounds, and better peat mineralization by microorganisms (Vomperskiy, 1968; Orlov and Koshelkov, 1971; Vaganov and Kachaev, 1992; Denisenkov, 2000). Given that the impact of November precipitation on growth is explained by a group of factors, we could expect a closer correlation to total precipitation in winter months in our case. Such a closer correlation appears indeed in two out of five chronologies (the correlation coefficient to total precipitation from March to December is -0.33), but it is clearly weaker than the negative effect of November precipitation (r = -0.44…-0.51). For dry and semi-wet TGS, three chronologies also show a reliable correlation to November precipitation (r = -0.35…-0.41). We can rule out the direct destructive effect of precipitation of this very period on root physiology because there is already no root activity during this period even in south taiga (Orlov and Koshelkov, 1971). We should conclude that the identified relation does not come down only to the above-mentioned effects caused by a rise in the water table but has another ecological and physiological manifestation mechanism.

It is well-known that soil begins to freeze in October or November in Karelia (Chernobrovkina, 2001). Abundant November precipitation can impede soil freezing both through a water-table rise (Chernobrovkina, 2001) and through formation of snow cover that will hamper freezing processes (Kuchko, 1969). In any case, it leads to higher soil temperature and impedes development of cold resistance in roots. A close relation between soil temperature and cold resistance in roots was reported following the experiments preformed in central Finland (Sutinen *et al.,* 1998).

Impact of February weather – Abundant February precipitation has a negative effect on spruce growth and a positive one on pine growth in semi-wet TGS. The negative impact of February precipitation on spruce growth can be associated with the effects of snow-thrown trees (Davydov, 1932; Vorontsov, 1978; Nykanen *et al.,* 1997). However, spruce trees are believed to be more resistant to snow loads than pines (Nykanen *et al.,* 1997).

On the other hand, spruce trees have a shallow root system and therefore can suffer from spring perched water. It is well-known that spruces are sensitive to stagnant moisture including situations of short duration (Orlov, 1966; Mironov, 1977). The spruce tree growing in the pine forest of a Ledum type is slightly less sensitive to abundant February precipitation than the spruce tree from the green bog moss forest (the correlation coefficient of – 0.37 vs. – 0.49). The same reaction is observed for the spruce tree from the Source Hill (r = - 0.49). In general, if the negative impact of February precipitation on growth is associated with the effect of perched water, chronologies related to trees growing in different soil and hydrological situations should have significant differences in a response to February precipitation. Thus, the negative impact of abundant February precipitation on spruce growth is not clearly interpreted. It is probable that the both mechanisms are present.

There was no negative response of pine growth to abundant February precipitation in all types of forests. Besides, a specific positive reaction to this growth factor was observed in pine forests of Vaccinium and Myrtillus types. The pine forests of Vaccinium and Myrtillus types formed in sandy loam soils are likely to depend for their nutrition on soil moisture content, which is determined by an amount of precipitation that gets into soil after snow melting. In the same way, pine forests growing in sandy soil in the Scandinavian Mountains have a positive response to total precipitation in February, March and April while pine forests growing in peat soil do not show any similar reaction. (Linderholm, 2001).

Conclusion

1. Summer temperatures and February precipitation are the main factors that influence spruce growth in South Karelia. They account for 70% of annual radial growth variability. The negative impact of high summer temperatures does not become apparent in the year of growth formation but shows only the following year.
2. We established a negative relation to high December temperatures for pine trees from all types of growing sites (TGS). The impact of precipitation on pine growth takes different forms in different TGS and it is particularly evident in the extreme growing conditions. A specific positive relation was established between pine growth and June precipitation for dry TGS. In semi-wet TGS, the same type of relation was observed for February precipitation. There was a negative relation between growth and November precipitation in wet TGS under high bogging conditions.
3. The negative impact of high temperatures of some months on radial growth gives a good reason to believe that the global warming may affect productivity and sustainability of conifer forests in South Karelia in a number of negative ways. High summer temperatures will cause reduced spruce growth. Pine growth may decline in all forest types due to destabilization of seasonal tempering rhythms under the influence of high December temperatures.

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