

Dendroclimatic research on Scots pine growing under the conditions of the raised bog in the Volga-Kama region, Russia

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Abstract. The radial growth dynamics of Scots pine in a large raised bog located in the territory of the Volga-Kama Nature Reserve, Republic of Tatarstan, has been studied. The master chronology correlated positively with the total amount of precipitation in January and negatively with the mean monthly temperature in June. Based on a complex analysis of temperature and precipitation in different months using hierarchical regression trees, three scenarios resulting in increased, average, and decreased radial growth have been suggested.

1. Introduction

Current changes in climatic parameters and subsequent reactions of forest communities at the regional level as a reflection of global environmental transformations are of great importance. Tree plants are the most suitable objects in evaluating these processes, because they are able to capture ecological information with their annual rings [1, 2, 3]. As a result of climate change, it is of special interest to investigate the natural ecosystems under pessimal conditions, i.e., when every minor fluctuation meteorological characteristics (temperature and precipitation) may lead to significant changes in the metabolism of plants [4, 5]. The purpose of this paper is to evaluate the effect of natural and climatic factors on the growth of trees in a large raised bog in the Republic of Tatarstan, the conditions of which can be characterized as pessimal. This bog is located in the territory of the Volga-Kama Nature Reserve, on the southern border of the boreal ecotone. Considerable factual material on the effect of climatic factors on the radial growth of trees has been accumulated in the scientific literature, but available current data on the radial growth of trees in the Volga-Kama region, bog habitats in particular, are insufficient.

The geographical location of the Republic of Tatarstan is not favorable for bog development. Due to the continental climate and the drainage degree of watersheds, along with the well-developed river network, bogs develop mainly in the river valleys. Thus, this territory is dominated by lowland bogs [6]. Sphagnum bogs appear as a result of atmospheric precipitation on depleted sandy soils.

The border between the following two bog zones runs along the territory of Tatarstan: raised pine-sphagnum and lowland grass bogs (East European province), which cover the pre-Kama area, as well as lowland sedge and reed bogs (Central Russian province), which stretch along the pre-Volga and trans-Kama regions [7]. The border between these zones coincides with the isoline of the hydrothermal factor (1.0), which runs from Penza to Kazan and farther eastwards, along the 56th parallel [8]. The main forest-forming species of the Volga-Kama Nature Reserve is Scots pine (*Pinus sylvestris*). It accounts for 70% of the total forest area, thereby offering an attractive object for dendrological studies.



This paper is an attempt to single out the main climatic parameters associated with radial growth, as well as to suggest possible scenarios of radial xylem growth in Scots pine under the conditions of bogs in the Volga-Kama Nature Reserve.

The Volga-Kama Nature Reserve is located on the left bank of the Volga River, 25 km westwards of Kazan. The landscape is dune-hilly with hollows and ancient gullies. The absolute altitudes vary from 65 to 105 m. The soils are sandy, medium podzolic. Peat bogs of limnogenic origin appear in depressions between the dunes.

2. Material and methods

The sample plot was laid on a floating sphagnum bog of Lake Dolgoe (N 66°40' E 34°21'). The forest type is sphagnum-dwarf shrub pine forest with solitary spruce and birch trees. The grass-dwarf shrub layer is dominated by cotton grass (*Eriophorum sp.*), marsh Labrador tea (*Ledum palustre*), leatherleaf (*Chamaedaphne calyculata*), bog-rosemary (*Andromeda polifolia*), cranberry (*Oxycoccus palustris*), and sphagnum moss. Pine is represented by the following two life forms: f. *litwinowii* and f. *uliginosa*; the trees are 125-227 years old and range in height from 3.5 to 15 m, average diameter 19 cm, growth class Va.

The standard methods of dendrochronological studies were used [9]. Material was sampled from 78 trees using a Haglof increment borer at the height of 0.5 m from the root collar. The width of annual rings was measured with the help of a semiautomatic LINTAB-6 system with TSAPWin software package [10]. The wood-ring chronology was constructed and analyzed in the dplR package [11]. Trend was excluded from the individual chronologies of radial growth, because it was suggested that it reflects the age characteristics of trees. The trend was evaluated with the help of spline. The individual chronologies were standardized. In order to construct master chronology, trendless chronologies of individual trees having a low correlation with master chronology were excluded.

The reaction of radial growth of Scots pine to climate was identified based on data on the mean monthly temperature and precipitation amount at the Sadovyi weather station of Sadovyi (1948-2011) 5 km from the bog. The dynamics of correlation between the radial growth of trees and the weather factors was analyzed using sliding correlation.

The complex effect of climatic factors on the radial growth of pine was evaluated using regression trees with a set of rules to determine the radial growth [12]. These models were built with the help of the rpart package [13] in the R statistical programming environment [14]. Since the size of data series on temperature and precipitation is quite limited, it was decided to use as few rules as possible.

3. Result and discussions

Based on the chronologies of radial growth of model trees in the bog area under study, a generalized chronology (series length 196 years) was obtained (figure 1). According to the EPS test, the chronology embraces a sufficient amount of data from 1830 to 2010. Therefore, the subsequent analysis was based on the radial growth index over the last 180 years.

The analysis of the climatic data from the Sadovyi weather station, the nearest one to the studied area, over the last 60 years showed clear trends in rising mean annual temperature and total precipitation. The positive trend for air temperature and total precipitation was 0.02°C/year and 1.5 mm/year, respectively. The observed climate change in the territory of the region takes place in the winter-spring period.

In order to identify the main climatic factors defining the radial growth of Scots pine in the studied area, correlations between the radial growth index and the air temperature and precipitation during the period from September of the previous year to August of the current year were analyzed (Fig. 3). There was a statistically significant response of the radial growth of Scots pine to the precipitation amount in January ($r = 0.5$, significance level <0.01). The negative correlation with the temperature in June was ($r = -0.43$, significance level <0.01).

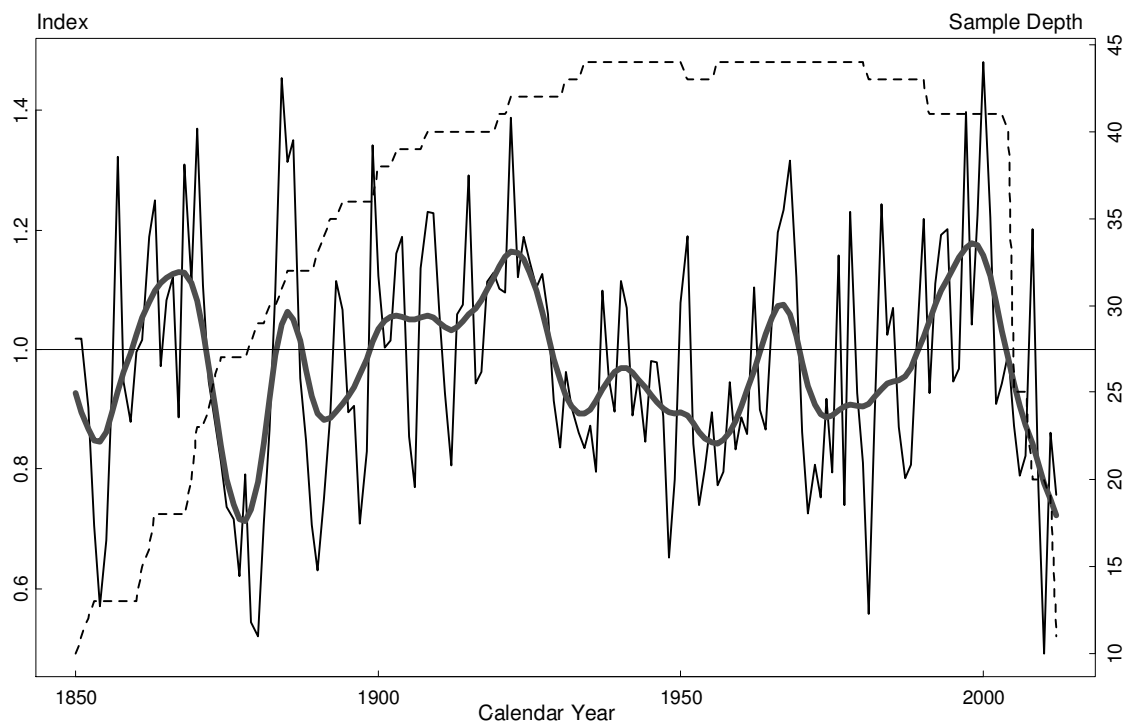


Figure 1. The long-term dynamics of the generalized index chronology DLG of the radial growth in Scots pine. The bold line shows the moving average index of radial growth, with a sliding window diameter of 30 years. The dashed line shows the individual growth chronologies involved in obtaining the master chronology.

The complex effect of climatic factors on the radial growth of Scots pine was evaluated using regression trees with a set of rules to determine the radial growth. Three scenarios resulting in increased, average, and decreased radial growth were elaborated.

The regression models also demonstrated that the key factors influencing the radial growth of Scots pine are the amount of precipitation in January and the average temperature in June, which corresponds to the data of the correlation analysis. The observed radial growth reaction is indicative of the characteristics of the site where the studied tree stand grows. The radial growth of Scots pine in the raised bogs on the southern border with the boreal ecotone depends on the amount of snow during the winter period. As it melts during the spring period, a moisture reserve for trees is formed. Large amounts of snow during the winter period can ease the arid and hot conditions of summer (advantageous scenario). A lack of snow during the winter period can be compensated by cold summer (neutral scenario). January with little snow and June with hot weather are non-advantageous scenarios leading to the formation of narrower annual rings in Scots pine under raised bog conditions.

4. Conclusions

The positive correlation of radial growth and the amount of winter precipitation proves that soil moisture plays an important role at the onset of vegetation. Further physiological activity of Scots pine depends on the summer temperature, which is especially important in the period of maximum radial growth of trees (June-July).

The sliding correlation showed that the climatic response of radial growth to temperature in June and the amount of precipitation in January, which were identified as the key factors as a result of the previous analysis, is not stable in time. This was mostly observed concerning the amount of precipitation in January. The importance of soil moisture reserve associated with the amount of winter

precipitation has increased for radial growth during recent decades. The unstable response of radial growth of Scots pine to temperature and precipitation is more likely to be caused by regional climate change over the recent decades as evidenced by the data of weather observations. Interestingly, this reaction may be demonstrated by trees not only because of the climatic fluctuations, but also due to changes in the groundwater regime and the cenogenesis of the raised bog.

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