Response of Scots pine ecotypes in geographical crops to climate change

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Abstract. The current sanitary condition of trees and stands of forest-steppe and steppe ecotypes of Scots pine is considered in relation to responses to climate change. Based on wood cores taken from 96 model trees in 62-year-old seed progenies of pine of different geographical origin on 32 sample plots, trends in the change in the width of annual rings and their structure by calendar years are established, and the magnitude and nature of responses of tree growth of different pine ecotypes to climate change are shown.

1 Introduction

The end of the 19th – beginning of the 21st century coincided with the era of increasing temperatures on our planet within the boundaries of the 1850-year cycle, which in turn consists of shorter 80-90-, 30-35-, 22- and 11-year cycles [1]. During the past period, it has been proven [2, 3] that natural ecosystems, compared to cultivated and pure phytocenoses, are more flexible and have a higher level of species, genetic, biological and ecological diversity. It has been established that in warm and humid years, the width of the layers of early and late wood is noticeably greater than in dry or arid years. In addition, the changes in the width of annual rings and their structure (the proportion of early and late wood layers in %), the trends in their dynamics by growth stages (young, middle-aged, maturing, mature and overmature) and by specific calendar years are greatly influenced by the changing climatic conditions of the region (temperature, precipitation, humidity, hydrothermal coefficient) of the previous year [1, 3, 4].

It is known that annual rings of wood in tree species consist of two components that differ in density, color, structure, anatomical structure and, as a rule, are unequal in width – layers of early and late wood [5, 6]. Thus, it is the annual rings of tree species and their anatomical structure that are a reliable keeper of the most valuable bioinformation about the influence of climate on the growth of trees and plantations over the past centuries, the study of which is the subject of the science of «dendrochronology» [1, 4].

A number of scientific articles are devoted to the study of post-fire successions of natural coniferous forests [7, 8] and their restoration in different forest growth zones and regions, as well as the growth dynamics of surviving slightly, moderately and heavily damaged forest stands in changed forest growth conditions [9, 10]. A number of works

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cover the process of organizing environmental monitoring of forest ecosystems, populations, forest stands and stands of individual forest-forming species [11], while others are devoted to the deterioration of the sanitary condition of forest stands, the impact of man-made pollution of the environment and unregulated forest recreation [12, 13, 14].

A clear manifestation of the response of wood layer growth is observed only with long-term and stable changes in weather conditions, for at least 1-1.5 decades of the vegetation period. Less often, climatic conditions of previous years have an effect on growth [15].

The vital state of the tree itself, which is assessed according to the "Rules of Sanitary Safety in Forests" [16], plays a major role in the very complex structure of the assimilation apparatus of Scots pine. At the same time, the response of individual trees and stands of seed progeny of Scots pine of different geographic ecotypes, concentrated in one testing ground of geographic forest cultures, created under the leadership of Professor M.M. Veresin in 1959, to climate change remains unstudied to this day.

2 Materials and methods

The object of the research was 59-61-year-old offspring of different geographical forest-steppe and steppe ecotypes of Scots pine at the Stupino Field testing ground in the Voronezh Region. During the vegetation periods of 2018-2020, 32 sample plots were laid out in geographical forest cultures, including 18 pcs. in forest-steppe ecotypes and 14 pcs. in steppe ecotypes [17]. In each sample plot (SP), a continuous count of trees was carried out with measurement of the diameter of their trunks at a height of 1.3 m with a measuring fork with an accuracy of 0.1 cm and with a simultaneous assessment of the sanitary condition according to the scale of the current «Rules for Sanitary Safety in Forests» [16].

The current survival of trees on the PP was determined as a percentage by dividing the number of growing trees by the initial planting density of seedlings (13.0 thousand pcs./ha). Other forestry and taxation indicators of tree stands were determined using generally accepted forest taxation methods.

The names of the geographic ecotypes in the text and tables are given according to the names of the forestries where the seeds were collected in 1956.

In the spring of 2021, at each PP, radial wood cores were taken from three model trees of medium diameter and height on the western side using a Haglof-60 age borer at a height of 1.3 m, belonging to the category «without signs of weakening».

Wood cores were dated from its periphery to the core of the tree trunk, starting from the last complete ring of 2020. Using the Lintab-6 measuring complex and the TsapWin program [18], the width of each annual ring, as well as the width of the early and late wood layers, was measured (Figure 1).

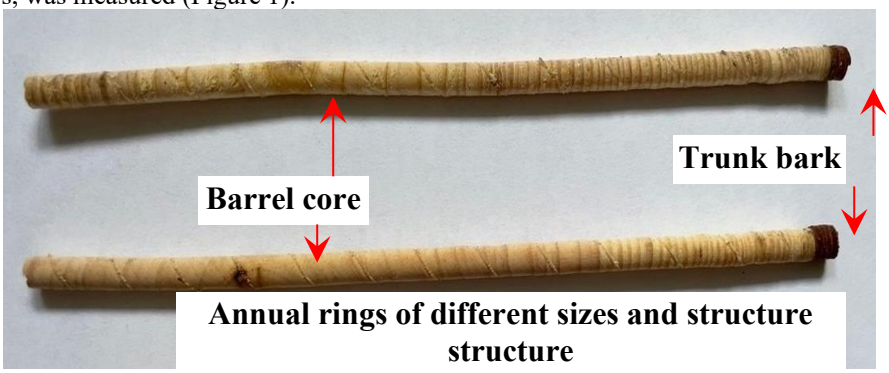

Fig. 1. Wood cores taken at a height of 1.3 m on the western side of average 62-year-old model trees of forest-steppe (top) and steppe (bottom) ecotypes.

In total, more than 5.0 thousand annual rings were measured, dividing them into early and late wood layers. The results were processed using Excel-16 computer programs.

3 Results and their discussion

One of the objective criteria for identifying the presence and assessing the degree of influence of climate change on the growth of seed progeny of different geographic ecotypes is a comparative assessment of the current preservation of trees in them on the date of planting the PP.

As the trees grew older, competition between the plants planted in 1959 became more intense both within rows and between adjacent rows. At the same time, in the course of natural selection, intraspecific and individual variability of tree growth and development, as well as their response to climate change by vegetation periods and calendar years, their differentiation into leading, middle and lagging occurred, determining the internal structure of micropopulations of a particular pine ecotype and their current preservation, as well as the corresponding current sanitary condition at a particular age and the amount of natural mortality in different age periods.

Information on the current preservation of trees in PP in forest-steppe and steppe pine ecotypes is given in [17].

The current (as of the dates of the PP establishment) preservation of 59-61-year-old trees varies within a fairly wide range. Thus, the maximum preservation for forest-steppe ecotypes is characteristic of PP 9-18 (B. Stalin ecotype of the Kursk region - 10.15%), and the minimum - for PP 1-18 (Khrenovsky ecotype of the Voronezh region - 3.54%).

he maximum preservation of trees in forest stands of steppe ecotypes is characteristic of PP 26-20 – 7.54% (B. Mikhailovsky ecotype of Dnepropetrovsk region), and the minimum (2.46%) – for PP 21-20 (Rakhinsky ecotype of Volgograd region). We did not establish any pattern in the placement of tree loss sites on PP in the rows of forest-steppe and steppe pine ecotypes.

According to the data of the continuous census, it was established that the current survival of trees in the PP in steppe pine ecotypes differs from forest-steppe ones and varies within the range from 2.5 to 7.5%. Its average value in the progenies of forest-steppe ecotypes is 7.1%, and in steppe ones it is less - 4.8%. The obtained results are statistically significant and confirm the differences in the adaptive potential of steppe ecotypes in forest-steppe conditions, as well as their different reactions to climate change ($t_{0.95} = 3.69 > 1.98$).

Examples of changes in trends of radial growth of average model trees by calendar years in forest-steppe and steppe ecotypes for clarity and comparability are presented in Figure 2, respectively.

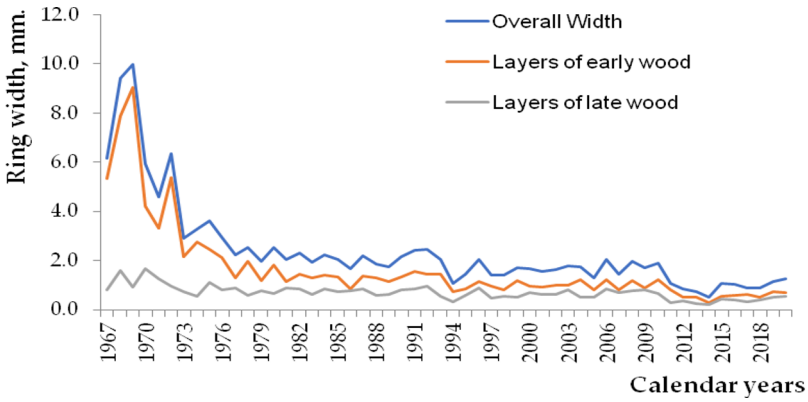

Fig. 2. Trends in the change in the total width of growth rings, layers of early and late wood for calendar years in average model trees at PP-1-18 (Khrenovskoye ecotype of the Voronezh region)

Based on the nature of the identified directions of radial growth trends, we identified three age stages of their change:

- the stage of increasing the width of annual rings after the start of active growth of seedlings in height and diameter and until the complete closure of young trees, which occurs at the age of 10 years;
- the stage of decreasing the width of annual rings from 10 years to 18 years (for forest-steppe ecotypes) and up to 20 years (for steppe ecotypes);
- the stage of stabilization of radial growth from 18-20 years of age to the present

Due to the fact that wood cores from model trees were extracted at the end of April 2021, the annual ring was not formed for this calendar year. Therefore, dating of annual rings on cores was carried out from the 2020 calendar year. False and dropped rings were not detected.

When analyzing data on the width and structure of annual rings by calendar years, obtained at 32 PP, it was established that an increase in the total width of rings in forest-steppe and steppe ecotypes was observed synchronously in the same calendar years: 1967, 1978, 1990 and 2004, characterized by temperatures below their average long-term values and humidity exceeding their average long-term parameters.

A decrease in the total width of annual rings and, accordingly, the earlywood and latewood layers in all ecotypes was observed in the following years - 1972, 1975, 1992, 2003 and 2010. However, the response to climate warming or cooling in individual calendar years in forest-steppe and steppe ecotypes differs both in the absolute value of annual growth and in the relative (%). Thus, the dynamics of the width of latewood layers, due to a shorter period of their formation (a warmer and drier half of the growing season compared to spring) by calendar years is more stable and less variable compared to the earlywood layers. It has been established that forest-steppe and steppe ecotypes respond differently to climate change.

4 Discussion

Based on the analysis of data on 32 PP in the stands of two groups of seed progeny of pine ecotypes, it can be concluded that the best vital condition is possessed by its forest-steppe ecotypes: 1.2 points Kolodezsky from Lipetsk, 1.3 points Urazovsky from Belgorod and 1.3 points B. Stalinsky from Oryol regions, in which the signs of plasticity to changing climatic conditions are fixed genetically. The worst sanitary condition is characterized by steppe ecotypes of pine from Saratov region (2.6 points). The assessment of the condition of

stands of 59-61-year-old geographical cultures of Scots pine in new growing conditions shows that a higher average score is possessed by ecotypes, the seeds of which were brought from the regions adjacent to Voronezh with similar or close natural and climatic conditions.

In general, for the entire set of tree stands on the PP in forest-steppe ecotypes, the average weighted condition score is 1.6±0.06 points, and on the PP in steppe ecotypes - 1.8±0.13 points. Among the group of forest-steppe ecotypes, the best current preservation was shown by the B. Stalinsky ecotype from the Kursk region (10.5%), and the worst - by Khrenovsky (3.54%) from the Voronezh region and Platonovsky (3.65%) from the Tambov region.

The average statistical values of the total width of annual rings in the model trees of steppe ecotypes are significantly higher than in forest-steppe trees (2.346±0.210 and 2.065±0.197 mm). A similar situation was found in these two groups of ecotypes for the width of the earlywood (1.360±0.148 and 1.182±0.130 mm) and latewood (0.986±0.072 and 0.882±0.071 mm, respectively) layers.

The tree-ring width parameters of forest-steppe and steppe pine ecotypes in geographic forest cultures provide a clear understanding of the response of plant growth to climate change and can be considered as their positive or negative responses for their assessment in past historical periods. The response of trees to precipitation compared to temperature is expressed more clearly from May to June.

5 Conclusions

Seed progenies of steppe ecotypes are more adaptive and actively respond to changed climatic and forest growth conditions, expressed in increased values of radial increment compared to forest-steppe ecotypes by calendar years and growth stages (up to 10 years, 11-20 years and 41-60 years), which predetermine a lower economic and technical value and quality of their stem wood throughout all growth stages. Consequently, in order to increase the economic and technical value of stem wood, it is more expedient to create new pine forests in the forest-steppe forest growth zone of the European part of the Russian Federation from local forest-steppe ecotypes that are promising in terms of a set of features.

Thus, when reproducing pine forests of the future in a given region, it is necessary to use seeds and planting material only from local populations that are resistant to climate change.

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