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INFLUENCE OF CLIMATIC FACTORS ON RADIAL GROWTH OF *PINUS STROBUS* L. AND *PINUS PEUCE* GRISEB. IN MOSCOW REGION

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Abstract

Most dendrochronological studies on conifers in Moscow region and on Russian plain in general focused to Scots pine (*Pinus sylvestris* L.) and Norway Spruce (*Picea abies* (L.) Karst). This study is focused on the chronology analysis in non-native pines from *Strobi* section: Eastern white pine (*Pinus strobus* L.) and Macedonian pine (*Pinus peuce* Griseb.) in Moscow city, Moscow region and some neighboring regions, with particular attention to climatic signal in tree-ring chronologies. The study revealed climatic factors that significantly correlate with the growth dynamics of the tested trees. The studied chronologies contained a drought-associated climatic signal, and the nature of the signal differed among the species and among chronologies of the same species obtained from various geographical areas. The most important effect had the climate conditions in May, both for different locations and for different species. The cluster analysis showed similarities in chronologies of the white pine for sites located in a closer proximity to each other, thus proving that site-specific ecological conditions influenced the growth dynamics in a specific manner. This regular pattern can be used as a basis for developing methods of wood origin identification.

Key words: dendrochronology, dendroecology, drought impact on radial growth, Eastern white pine, Macedonian pine, wood origin identification.

Introduction

Most dendrochronological and dendroecological studies on the conifers in Moscow region and on the Russian plain have been performed on Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst) (Solomina et al. 2017). Such kind of investigations may have importance for progress in the forestry practices and can provide unique information about the ecological patterns of growth, which often cannot be obtained from other sources (Rumyantsev 2010).

On the one hand, the impact of climatic variability on radial growth fluctuations is closely related to hereditary ecological properties of the studied species, mainly to such characteristics like tolerance to drought, heat, frost, and cold.

On the other hand, local growing conditions affect the formation of patterns of annual radial growth fluctuations. Consequently, being unmatched in time the tree ring width fluctuation patterns appear to be similar in all trees of the same species growing in homogeneous site conditions. This regular pattern serves as a basis of many methods to identify the origin of logged timber, as shown in the publications devoted to this issue (Rozanov 1969, Palchikov and Rumyantsev 2009, Sinkevich 2014, Goncharuk and Mayorova 2015, Voronin et al. 2016).

In this study, we examined chronologies of Eastern white pine (*Pinus strobus* L.; called hereafter 'white pine') and Macedonian pine (*Pinus peuce* Griseb.) from Moscow city, Moscow region and some other regions for comparison. These species are evolutionarily closely related to each other (Eckenwalder 2009). White pine has long been considered a promising species for wide introduction in Russia for the purpose of timber producing plantations. However, the sensitivity of this species to the White pine blister rust (*Cronartium ribicola* Fisch) did not allow this program to be implemented (Tsarev et al. 2002).

Our knowledge of regularities of annual rings changes helps the better understanding of their ecological significance, and understanding the ecological conditions favorable for cultivation of a given species in the long-term perspective. Dendroecological study of these two species in the Russian regions has not been performed before. Therefore, the results of such study would be of general biological significance, revealing the effect of climatic factors on the growth of species cultivated far from their natural range and located in unusual (that is, stressful by definition) conditions.

Dendroclimatic investigations in the natural range of white pine performed with bootstrapped correlation analysis indicated that the radial growth was negatively associated with summer temperature (i.e., June and July) of the current growing season in both floodway and terrace sites (Chin et al. 2013).

In other part of the white pine natural range, dendroclimatic models revealed that radial growth responses to climate were complex and differed among sites (Chin et al. 2018). The key dendroclimatic relationships observed included sensitivity to high temperature in winter and summer, cold temperature in the spring and fall (i.e., beginning and end of the growing season), summer moisture stress, potential sensitivity to storm induced damage in spring and fall, and both positive and negative effects of higher winter snowfall. Separation of the loadings of provenances on principal component axes was mainly associated with temperature-related bioclimatic parameters of provenance origin at 5 of the 7 test sites close to the climate influence of the Great Lakes (i.e., Wabeno, Manistique, Pine River, Newaygo, and Turkey Point). In contrast, differences in radial growth response to climate at the Ganaraska test site were driven more by precipitation-related bioclimatic parameters of the provenance origin location, while radial growth at the easternmost Orono test site was independent of bioclimate at the provenance origin location. Study results suggest that genetic adaptation to temperature and precipitation regime may significantly influence radial growth performance of white pine populations selected for use in assisted migration programs to better adapt white pine to a future climate.

The great interest also has the results of the investigation of tree-ring chronology of *Pinus peuce* from treeline locations in the Pirin Mountains in Bulgaria showed the strong climatic signal (Panayotov et al. 2010). Climate-growth relationships were computed with bootstrap correlation functions and their consistency over time assessed by calculating the correlations over shortened periods. In addition, climate situations in the years with unusually narrow or wide tree rings were reviewed and analyzed. The species is negatively influenced by previous summer drought conditions and cold winters. Early summer temperatures were positively correlated with *P. peuce* radial growth.

The comparison of radial growth models in the natural area with results the growth investigation in introduction is important for understanding the ecophysiological potential of the species. The purpose of our study was to investigate the interannual variability of tree rings width of Eastern white pine and Macedonian pine and to establish how climatic factors impact radial growth in time series and how this impact can be modified by genetical ecophysiologies features of the species or local environment condition.

Materials and Methods

This study involved materials collected in the Arboretum of Mytischi Branch of Bauman of the Moscow State Technical University (the university was known under the name Moscow State Forest University (MSFU) until 2016, so we use name “MSFU Arboretum” further in the article), the Main Moscow Botanical Garden of Russian Academy of Sciences, the Botanic Garden of Moscow State University, and the Pereslavl Arboretum (Yaroslavl region), Ahunsky Arboretum (Penza), Ugra National Park (Kaluga region), Poreczkoe Forestry Service (the west of Moscow region).

Wood samples were obtained using a Pressler increment borer; cores were taken from the trees at a height of 1.3 m with a spot on the stem being chosen at random and the samples were stored in paper envelopes until used. The following details were recorded for each core: test site, species, tree ID, sample ID, Kraft’s tree class (tree position in the stand social structure and its crown development and extent), height, diameter, and direction of sampling. Then, the collected and labeled samples were delivered to the Dendrochronological Laboratory of the Science and Education Center for Wood Investigation, Analysis and Expertise of MSFU to perform measurements with the LINTAB equipment in combination with the TSAP-Win software.

The cores were placed in a wooden background and the surface of the cores was wetted with water, cleaned with a razor blade and rubbed with chalk powder. This contributed to the clear recognition of the boundaries of annual rings. Tree ring widths were measured with a precision of 0.01 mm. Cross-dating was carried out to verify the measurement results in TSAP-Win program. The methodology is similar to one described in previous papers (Lovelius et al. 2013, Rumyantsev and Cherakshev 2013). The obtained radial growth series were indexed by dividing of tree ring width to the average tree ring width observed in the last five years. Next, a mean group chronology was calculated for each species from each geographic area based on individual indexed chronologies. The parameters of testing generalized chronologies are presented in Table 1.

The distribution of plots in the territory of Russian plain is shown in Figure 1. The main topic of scientific interest was the tree ring variability of Strobi pines in Moscow region, but for good understanding of its specific patterns it was necessary

Table 1. Parameters of testing chronologies.

Object	Species	Individual chronology with maximum length, years	Number of testing trees	Number of cores	Number of measured tree rings
MSFU Arboretum	White pine	1962–2013	5	10	481
	Macedonian pine	1978–2013	12	24	701
Main Botanical Garden of Russian Academy of Sciences	White pine	1963–2014	12	24	1115
	Macedonian pine	1965–2014	12	24	1060
Botanic Garden of Moscow State University	White pine	1963–2014	4	4	169
Pereslavl Arboretum	White pine	1979–2013	7	14	419
Poreczkoe Forestry Service	White pine	1918–2018	25	25	2364
Ugra National park	White pine	1915–2018	10	10	788
Ahunsky Arboretum	White pine	1920–2017	17	17	1216
Sum			104	152	8313

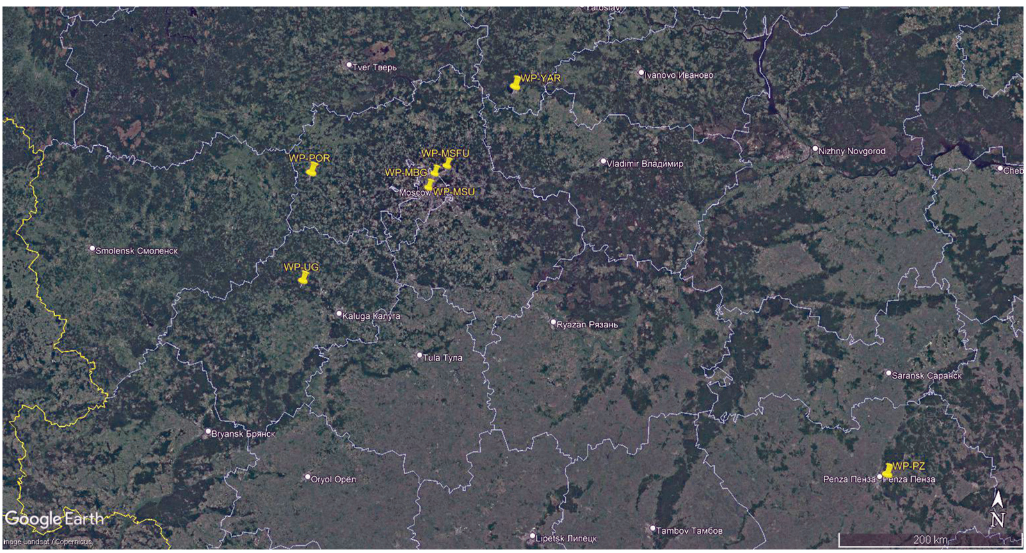

Fig. 1. Geographical location of sample sites (from Google maps).

Note: sample site locations: WP-PZ – Ahunsky Arboretum in Penza region; WP-YAR – Pereslavl Arboretum in Yaroslavl region; WP-MSU – MSU arboretum in Moscow; WP-MSFU – MSFU arboretum in Moscow region; WP-MBG – MBG arboretum in Moscow; WP-UG – Urge National Park in Kaluga region; WP-POR – Porezckoe forestry arboretum at the west border of Moscow region.

to investigate different plots situated at some distance from Moscow. Therefore, the possibilities for choice the study areas were not vast. Plots situated westward from Moscow (WP-PZ), south-west (WP -UG), north-east (WP-YAR), south-east (WP-PZ, the most remote site) were sampled.

Such kind of plot distribution allowed to study the possibilities of identifying the place of origin of felled wood according to dendrochronological data. Also, it was important for analyzing the specific patterns of the influence of climatic factors on the dynamics of radial growth. Only two of study areas had the stands formed by the Macedonian pine. They were located in Moscow and Mytischi town (near the border line of Moscow city and in fact, in Moscow from a biogeographic point of view). The analysis of the dynamics of radial growth of this species was compared with that of Eastern white pine, which was important in the light of their biological and ecological proximity, with considering the specific ecological requirements of Macedonian pine.

All calculations were performed in Microsoft Excel. STATISTICA 6.0 was used for cluster analysis. This application has a wide statistic possibility for cluster group construction. At this research stage the simplest variant: Euclidean distance calculation and association in clusters by the rule of ‘single linkage’ was used. The question of the best option for clustering of dendrochronological information in dendroecological studies requires further studies.

The climatic data (2004–2021) from several sources were used: specialized meteorological web portal (Weather and Climate 2021), Pereslavl-Zalessky meteorological station, Moscow meteorological station, Penza meteostation, and for Ugra national park the data from Kaluga meteorological station were used.

The period for statistical analysis was limited by the length of all chronologies and was set to 1987–2013, as the trees had different age and the sampling took place in different years.

The climate of Moscow city was characterized by using the Main Botanical Garden data (Plotnikova et al., 2005), which can be considered as a central point in relation to the other test sites. The date of transition of the average daily temperature through 0 °C is marked in spring 5th of April and in autumn 5th of November, and hence the frost-free period lasts 214 days. The transition through 5 °C conventionally taken as the beginning of the growing season is observed in spring at 20th of April and in autumn at 5th of November. The duration of the growing season is 173 days. The average annual air temperature is 3.7 °C, the absolute minimum is -40.8 °C, the absolute maximum is 35.8 °C. The soils are loamy sod-medium podzolic (Umbric Albeluvisols Abruptic).

The conditions of tree growth in plantings are similar to the conditions of their growth in natural stands. This was one of the goals for testing their growth in introduction in order to assess the possibilities of using species in the forestry practice. The stands had not experienced currently any intensive sylviculture treatment such as irrigation, fertilization and so on; however, for some sites there is lack of information about their treatment in the past.

Results and Discussion

The generalized indexed chronologies of white pine were analyzed using a cluster analysis method with the STATISTICA 6.0 software. Figure 2 shows the results.

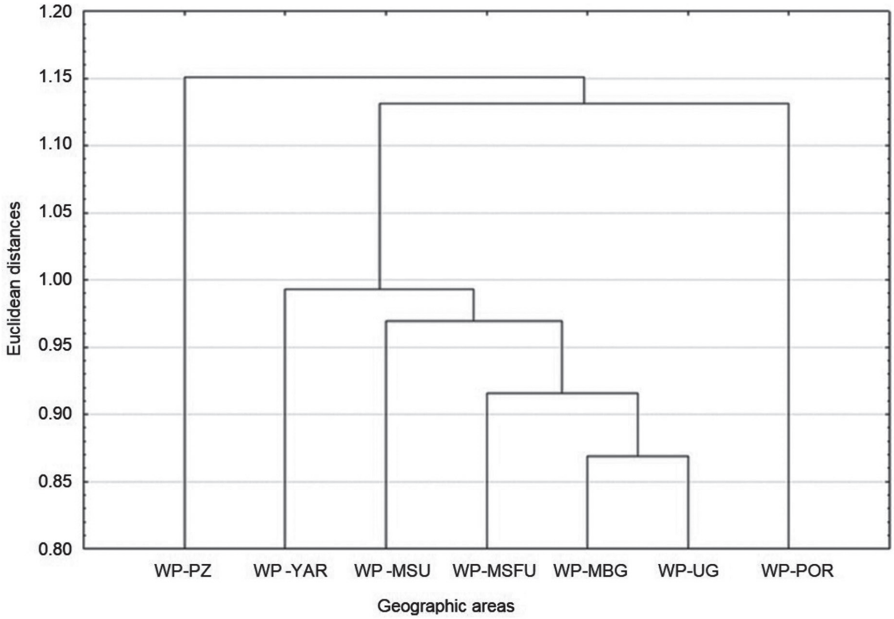

Fig. 2. Results of the cluster analysis of the indexed tree-ring chronologies of white pine in various geographic areas.

Note: the chronologies of *Pinus strobus* are plotted on the abscissa by regions: WP-PZ – from Ahunsky Arboretum in Penza region; WP-YAR – from Pereslavl Arboretum in Yaroslavl region; WP-MSU – from MSU arboretum in Moscow; WP-MSFU – from MSFU arboretum in Moscow region; WP-MBG – from MBG arboretum in Moscow; WP-UG – from Ugra National Park in Kaluga region; WP-POR – from Porezckoe forestry arboretum at the west border of Moscow region.

As shown in Figure 2, a similarity range of chronologies within one species as a whole is in direct relationship with the pairwise distance between the sites. The chronologies obtained from the MSFU Arboretum are more similar to the ones obtained from the Main Botanical Garden located nearby, in the northeastern part of Moscow, than to those from the Botanic Garden of Moscow State University located in the southwestern part of Moscow. However, together they form one cluster when compared to the chronology from Yaroslavl region (Pereslavl Arboretum, about 130 km from Moscow) and Poreczkoe forestry service (about 77 km from Moscow). The chronology from the Penza region (about 550 km from Moscow) opposes the entire large cluster of chronologies as an equivalent cluster, which is expected in the light of its remoteness. Only the chronology of Ugra Park (about 180 km from Moscow) had a position in cluster, which is not correlating with its geographical location.

The cluster analysis really is a complex of methods, with different variants to organize the group. Some of groups may have biological interpretation, some of them no. Our results indicates that the established method of clustering gives a good biologically interpretable results, but does not fully meet the needs of dendroecological research yet and the statistical processing could be improved.

Another important and indicative indicator is the correlation coefficient among the chronologies and time series of meteorological parameters (sum of monthly rainfall, average monthly temperature). In the present study we used both meteorological parameters of the year of tree ring formation and those of the preceding year (tables 2–6).

Table 2. The values of the correlation coefficients between chronologies and average monthly temperatures in the year of the formation of the annual ring.

Month	Site ID / Correlation coefficient							NSCC
	WP-MSFU	WP-MBG	WP-MSU	WP-YAR	WP-PZ	WP-POR	WP-UG	
I	0.04	0.04	0.32	-0.15	0.39*	0.31*	0.09	2
II	0.23	0.23	0.18	-0.27	0.53*	0.36*	-0.24	2
III	0.05	-0.11	0.07	-0.05	0.47*	0.10	-0.05	1
IV	0.21	0.15	0.26	-0.28	0.35*	0.02	0.14	1
V	-0.46*	-0.43*	-0.26	0.02	-0.44*	-0.41*	-0.31*	5
VI	-0.33*	-0.12	0.01	-0.21	-0.47*	-0.02	-0.24	2
VII	-0.10	-0.23	0.18	-0.19	-0.18	-0.04	-0.21	0
VIII	-0.17	-0.19	0.11	0.26	-0.05	0.02	-0.11	0
IX	-0.01	-0.20	0.13	0.05	-0.30	0.08	0.14	0
X	0.13	0.19	0.29	0.21	-0.02	0.23	0.26	0
XI	0.19	0.00	0.11	0.25	0.00	0.12	0.18	0
XII	0.19	0.25	0.25	0.39*	0.08	0.15	0.28*	2
NSCC	2	1	0	1	6	3	2	15

Note: * – significant correlation coefficient for the confidence level of 0.95; NSCC – number of significant correlation coefficients.

Table 3. The values of the correlation coefficients between chronologies and average monthly temperatures in the year preceding the year of the formation of the annual ring.

Month	Site ID / Correlation coefficient							NSCC
	WP-MSFU	WP-MBG	WP-MSU	WP-YAR	WP-PZ	WP-POR	WP-UG	
I	0.25	0.20	0.05	-0.18	0.26	0.12	-0.06	0
II	0.29	0.10	0.02	-0.08	-0.02	0.17	-0.01	0
III	0.38*	0.20	-0.13	-0.05	-0.09	0.05	0.13	1
IV	0.18	0.01	0.00	-0.47*	-0.11	0.04	0.03	1
V	-0.03	-0.19	0.08	0.49*	-0.35*	0.04	-0.16	2
VI	0.21	0.21	0.19	-0.22	-0.02	0.27	-0.01	0
VII	0.14	0.05	0.35*	-0.08	0.00	0.12	0.04	1
VIII	-0.01	-0.09	0.21	0.15	-0.15	0.12	-0.04	0
IX	-0.02	-0.08	0.07	-0.03	-0.02	-0.11	0.02	0
X	0.25	0.14	0.40*	0.06	-0.03	0.23	0.35*	2
XI	-0.20	-0.39*	-0.01	0.22	-0.10	-0.13	-0.09	1
XII	0.29	0.19	0.50*	0.36	0.19	0.26	0.32*	2
NSCC	1	1	3	2	1	0	2	10

Note: * – significant correlation coefficient for the confidence level of 0.95; NSCC – number of significant correlation coefficients.

Table 4. The values of correlation coefficients between chronologies and monthly precipitation sums in the year of the annual ring formation.

Month	Site ID / Correlation coefficient							NSCC
	WP-MSFU	WP-MBG	WP-MSU	WP-YAR	WP-PZ	WP-POR	WP-UG	
I	0.01	0.07	0.26	-0.03	0.13	-0.05	0.19	0
II	0.24	0.16	0.26	-0.07	0.10	0.11	-0.04	0
III	0.23	0.36*	0.28	-0.11	0.26	0.17	0.11	1
IV	-0.01	0.06	0.17	0.27	0.24	-0.15	0.12	0
V	0.50*	0.43*	0.22	0.22	0.20	0.05	0.01	2
VI	0.13	0.13	-0.05	0.14	0.55*	0.14	-0.13	1
VII	0.51*	0.51*	0.17	0.31	0.31	-0.01	0.02	2
VIII	0.14	0.26	0.02	0.19	-0.01	-0.13	0.15	0
IX	-0.26	-0.04	-0.14	-0.02	0.17	0.17	-0.20	0
X	-0.02	-0.15	0.28	-0.08	-0.06	0.02	0.02	0
XI	-0.08	-0.12	-0.02	0.19	0.07	0.06	-0.07	0
XII	0.13	0.11	-0.02	-0.15	-0.04	0.02	0.03	0
NSCC	2	3	0	0	1	0	0	6

Note: * – significant correlation coefficient for the confidence level of 0.95; NSCC – number of significant correlation coefficients.

Table 5. The values of the correlation coefficients between chronologies and monthly precipitation sums in the year preceding the year of the formation of the annual ring.

Month	Site ID / Correlation coefficient							NSCC
	WP-MSFU	WP-MBG	WP-MSU	WP-YAR	WP-PZ	WP-POR	WP-UG	
I	0,06	0,20	0,08	-0,23	-0,25	0,12	0,05	0
II	0,12	-0,10	-0,07	-0,55*	-0,14	0,08	0,11	1
III	0,04	0,07	0,05	-0,48*	-0,07	-0,05	-0,04	1
IV	-0,09	-0,06	0,07	0,30	0,08	0,04	0,38*	1
V	-0,20	-0,30	-0,05	-0,08	-0,30	-0,30*	-0,33*	2
VI	-0,36*	-0,17	-0,17	0,22	0,36*	-0,08	-0,03	2
VII	0,26	0,02	0,02	0,19	0,04	-0,09	0,10	0
VIII	0,24	0,25	0,30	0,04	0,24	0,13	0,28*	1
IX	-0,04	-0,17	0,13	0,05	-0,07	0,19	-0,23	0
X	-0,15	0,04	-0,12	-0,28	0,00	-0,25	0,05	0
XI	-0,16	-0,10	-0,06	-0,16	0,06	-0,11	-0,24	0
XII	0,02	-0,05	0,09	0,02	0,23	-0,02	0,21	0
NSCC	1	0	0	2	1	1	3	8

Note: * – significant correlation coefficient for the confidence level of 0.95; NSCC – number of significant correlation coefficients.

Tables 2–5 show that there were 24 meteorological parameters correlating significantly with the radial growth dynamics of white pine. The matrix of correlation coefficients includes 39 significant values out of 48 calculated as a whole. Some of them obviously do not have biological meaning and result from stochastic processes (mutual correlation of time series of meteorological parameters as an example). So, for chronologies from Perslavl (WP-YAR) and Ugra (WP-UG), a significant correlation with December temperature of recent calendar year was identified. It cannot be interpreted in biological terms, as the ring formation in this time is already over. On our opinion, the parameters of October, November and December of the current year must be present in dendroclimatic investigation for good understanding the level of biologically significant values, which must be higher than parameters for this month.

When the distribution of significant values of correlation coefficients by month was analyzed, the maximum number of such values was found in May (Fig. 3).

It explains the specific effect of vegetation season periods on the cambium activity and xylem differentiation, which reflect integrally the ring width. It is important to consider that May is the period of the most active shoot growth and assimilation surface forming, which apparently predetermines photosynthetic activity and opportunities for the formation of xylem, and this factor influences the ring width in the current year, and also in the next year.

While analyzing the distribution of significant values of correlation coefficients by chronologies, it was found that chronology from Penza region (WP-PZ) demonstrates the maximum number (nine) of such values. This area has a dry climate. High temperatures of vegetation season negatively affect the ring width, while high amount of precipitation has positive affect. At the same time, this result has good comparability with data from the natural habitat in North America (Chin et al. 2013), taking into account the shifted growing season.

In our research, there was not a single meteorological parameter detected, for which a reliable correlation was found for all chronologies. Also, we did not reveal any reliable correlations that would be valid for all investigated sites. This is confirmed with the results of investigation within the natural area of species distribution (Chin et al. 2018). For five sites the greatest importance for annual ring formation of white pine had the temperature of May, which had negative effect on ring

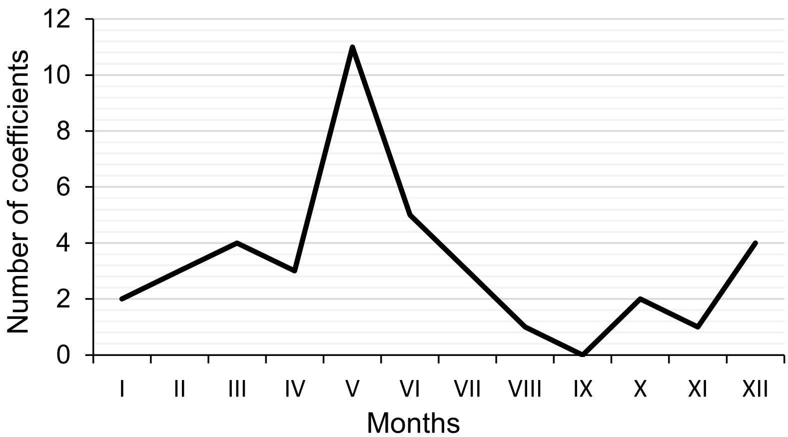

Fig. 3. The distribution of the number of significant correlation coefficient values by months.

width. Thus, if our hypothesis about irrigation the plantings of white pine in MSU and Pereslavl Arboretum on some time interval is right, that leads to conclusion that chronologies of white pine from Moscow region characterized the specific feature: express significant positive high-level correlation with the precipitation in May and July.

If we compare the effect of climate conditions of the current and the previous calendar year, it turns out that 21 reliable coefficients were found for the current year, and 18 for the previous one. The difference is not as great as one might expect, and we must consider that the influence of meteorological parameters on the tree ring formation continues also out of the vegetation period, when the cambium activity does not stop, as is well known from the Fritts (1976) models. The time of the period of the so-called ‘winter rest’ is in fact a period of stress state of the tree and has an integral indirect effect on its growth during the vegetation season.

The analysis the distribution of drought-related climatic signals in investigated chronologies is of particular interests, too. In this case, by drought-associated signals we mean significant positive correlations of the growth index with the total monthly precipitation of May, June, July and August, as well as reliable negative correlations with the monthly average temperatures over the same period. The coefficients of the current and previous year are taken into account. The calculations preformed for chronologies are presented in Table 6.

Thus, we can say that chronologies from two sites in urbanized environment contain a strong climatic signal caused by droughts, as does the chronology from the driest (of the investigated) region, which is situated in forest-steppe zone.

For Macedonian pine, a similar comparison of climatic signal distribution in chronologies taken from various areas was done only for the MSFU Arboretum and the Main Botanical Garden of Academy of Sciences. There were only a few Macedonian pine trees in Pereslavl Arboretum or the Botanic Garden of Moscow State University, and this species was not present at other sites. It is not appropriate to compare individual chronologies with the mean group chronologies based on ten or more trees. Table 7 presents the results of the correlation analysis.

As indicated in Table 7, the study revealed 12 meteorological parameters showing a reliable correlation with Macedonian pine radial growth indexes for at least one site under study. However, reliable correlations for both sites were observed only for the rainfall in May and in July of the current year. Higher rainfall has a positive impact on growth. These two meteorological variables were also the ones showing reliable correlations in white pine growing on the same two sites. The level of similarity in the short-term dynamics of growth among chronologies of the same species on different objects, and different species on the same object is of particular interest. One such graphical comparison is shown in Figure 4.

Table 6. Distribution of drought-associated signals in chronologies from different sample areas.

Code of chronology	WP-MSFU	WP-MBG	WP-MSU	WP-YAR	WP-PZ	WP-POR	WP-UG
Number of coefficients	4	3	0	0	5	1	2

Table 7. Correlation coefficients between individual meteorological parameters for Macedonian pine.

Meteorological parameter with a detected reliable correlation for at least one site	MSFU Arboretum	Main Botanical Garden of Academy of Sciences
Rainfall in May of the current year	0.43*	0.32*
Rainfall in June of the current year	0.43*	0.07
Rainfall in July of the current year	0.52*	0.60*
Rainfall in May of the preceding year	-0.43*	-0.28
Average temperature in June of the current year	-0.42*	-0.19
Average temperature in July of the current year	-0.36	-0.32*
Average temperature in August of the current year	-0.45*	-0.17
Average temperature in October of the current year	0.21	0.37*
Average temperature in December of the current year	0.1	0.37*
Average temperature in September of the preceding year	-0.39*	-0.05
Average temperature in November of the preceding year	-0.30	-0.33*
Average temperature in December of the preceding year	0.19	0.41*
Number of significant coefficients	7	7

Note: * – significant correlation coefficient at confidence level of 0.95.

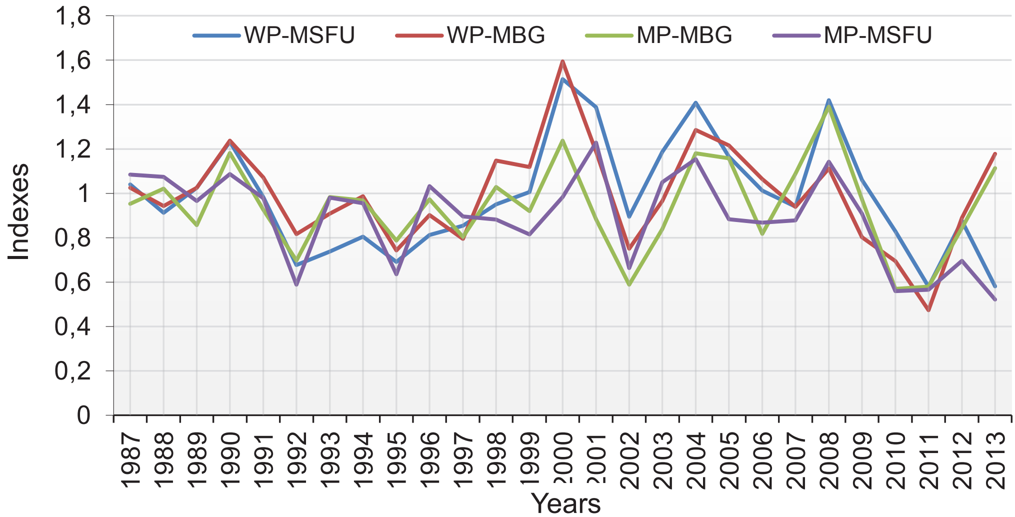

Fig. 4. Dynamics of radial growth indexes for two pine species.

Note: WP-MSFU – chronology of white pine from MSU arboretum in Moscow region; MP-MSFU – chronology of Macedonian pine from MSFU arboretum in Moscow region; WP-MBG – chronology of white pine from Main Botanical Garden arboretum in Moscow; MP-MBG – chronology of Macedonian pine from Main Botanical Garden arboretum in Moscow.

The time series presented in Figure 4 support the conclusion about great similarity of chronologies and high level of their synchrony, especially at the years of growth extrema. Also, the comparison of chronologies similarity is possible by using the results of the correlation analysis in Table 8. The coefficient was calculated between indexed chronologies for the period 1987–2013 years. At a confidence level of 0.95, the threshold values of significance were 0.38 or higher.

Table 8. Correlation coefficients between chronologies for White pine and Macedonian pine from different areas.

Code of chronology	WP-UG	WP-POR	WP-PZ	WP-MSFU	WP-MBG	WP-MSU	WP-YAR	MP-MBG
WP-POR	0.23							
WP-PZ	0.54	0.28						
WP-MSFU	0.70	0.19	0.57					
WP-MBG	0.69	0.30	0.57	0.72				
WP-MSU	0.54	0.14	0.34	0.54	0.61			
WP-YAR	0.28	0.26	0.06	0.37	0.16	0.41		
MP-MBG	0.54	0.46	0.41	0.59	0.77	0.52	0.34	
MP-MSFU	0.42	0.45	0.44	0.74	0.54	0.30	0.46	0.59

The correlation analysis presented in Table 8 showed that chronologies of different species from the same location have greater similarity than these of the same species from different locations. Therefore, the local conditions impact prevailed over the genetical and eco-physiological features of species in the tree ring dynamic from year to year.

Conclusions

Local growing ecological conditions determine that radial growth dynamic formed by a different combination of limited meteorological parameters, and this creates a diversity in growth dynamics in chronologies of the same species it the located geographical sites. Being associated to various genetical and ecophysiological properties of the planting material, such as provenance, genetic factors may also contribute to dynamics diversity of time series of radial growth.

The correlation analysis of the generalized indexed chronologies of white pine and Macedonian pine compared to time series of meteorological parameters (monthly rainfall and average monthly temperature) shows reliable correlations for both pine species that are common for the test sites situated close to each other. The results of correlation and cluster analyses allow the conclusion that specific site conditions can be more important in terms of growth rate dynamics that specify genetical ecological properties of a species. The response to rainfall shortage in May and July represents a clear drought-associated signal in the chronologies of these species in Moscow. Also, May temperature is a significant factor for white pine chronologies from Moscow region, Kaluga region and Penza, and has negative impact on ring width.

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