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RESEARCH ARTICLE

Dendrochronological analysis of the influence of climate on autochthonous and introduced coniferous tree species in the city park "Prostor", Kardzhali

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Abstract

The study focuses on the response to climate change of indigenous and introduced coniferous tree species – Austrian black pine (*Pinus nigra* Arn.) and Colorado spruce (*Picea pungens* Engelm.) situated in the urban city park "Prostor" in the town of Kardzhali. A multifactor regression analysis was used in the frame of the dendrochronological studies to establish the functional dependence "climate – radial growth". The model was tested in a climate window with a segment of 16 years – from 2005 to 2020. The data for air temperature and monthly precipitation amounts for Hydro-meteorological station (HMS) Kardzhali were used as predictors for the radial growth. = Both species's indifference to the temperatures and rainfalls during the months August and September, crucial for the ring formation, leads to the absence of significant growth depressions in tree-rings chronologies and justifies the good condition of the studied trees.

Keywords

Coniferous trees, urban park, dendrochronological analysis, climate

Introduction

The complex urban green system comprises heterogeneous small and large areas and linear elements connected to each other and with the city system with variable and non-linear rules (Menconi et al., 2021). Forest parks located in urban and peri-urban areas besides regulating, supporting, and providing services, also provide non-material benefits to people from ecosystems (MEA, 2005). The dendroflora is among the important elements of the landscape structure of the parks, which creates the overall look and vision, outlines the specifics, highlights the differences and creates a specific aesthetic view of a the park area. The use of afforestation materials from various local and introduced tree species is directly linked to the specific capabilities of selected tree species to provide high aesthetic qualities for as long as possible during the calendar year. Unlike deciduous tree species, whose biological feature is associated with leaf fall in autumn, coniferous tree species provide green leaf mass to the crowns throughout the year. This is one of the main reasons why coniferous tree species are an integral part of landscaping of city parks.

The general condition of the dendroflora in the parks depends not only on the anthropogenic factor (e.g. maintenance), but also on global factors such as the climatic conditions and specifics for a given region. The conditions of intensive climate change in recent years may play a negative role in the condition of the tree flora in the old city parks. This is valid for those areas in Bulgaria that are characterized by climatic conditions with prolonged droughts during the summer, such as the region of Kardzhali in SE part of the country. It has been found that periods of climate stress affect the functioning of the initial layer of cells in woody plants (cambium), and hence in the width of annual rings (Douglass, 1914, 1928; Fritts, 1976; Schweingruber, 1996, etc.). Prolonged (perennial) effects of climate stress lead to a weakening of the vitality of woody plants, and to the emergence of secondary stressors such as phytopathogens or insect pests on already weakened woody plants. In this sense, dendrochronology is emerging as an important scientific method that, through the analysis of annual rings, can reveal the strength and duration of the negative climatic impact on woody plants.

The **aim** of the present study is to disclose the influence of limiting climatic factors as air temperature and amount of the precipitation on the tree-ring width of native – Austrian black pine (*Pinus nigra* Arn.) and introduced – Colorado spruce (*Picea pungens* Engelm.) tree species in the city park "Prostor", Kardzhali.

City Park "Prostor" Kardzhali is no exception to the general trend and along with deciduous tree species, coniferous are another widely used afforestation material for planting. The native tree species for Bulgaria, such as Austrian black pine (*Pinus nigra* Arn.) and other, exotic for our country tree species, originating from North America, such as Colorado spruce (*Picea pungens*. Engelm.), were studied.

Material and methods

Twenty-four samples for dendrochronological analysis were taken from selected tree individuals from "Prostor" City Park in Kardzhali with a Pressler's drill (specialized probe for extraction of wood cores). Twelve adjacent Austrian black pine trees (*Pinus nigra* Arn.) and the same number of trees located in a homogeneous group of Colorado spruce (*Picea pungens* Engelm.) were selected and cored. The geographic coordinates of the studied Austrian black pine trees are: 41°38'34.14"N and 25°22'44.92" E, and the geographical coordinates of the group of Colorado spruce trees are: 41°38'32.91"N and 25°22'53.71"E.

After field sampling, in laboratory conditions, the drilling cores are mounted on special wooden holders and processed to obtain a polished-smooth surface that provides a clear visual identification of the histological elements in the xylem of each sample. Visual dating and cross-dating were performed using a Leica MS5 microscope. Specialized COFECA software was used to verify visual dating (Holmes et al., 1986). The radial growth by years was measured with an accuracy of 0.01 mm using a digital station for analysis of annual rings LINTAB 5 and TSAP Win software (Rinn, 2005).

The detrending process of the series was done using smoothing spline functions (Cook, Peters, 1981) with ARSTAN software package (Cook at al., 2006).

The obtained regression models for the trend of each tree and the measured values for the width of the annual rings allow us to calculate the indices for the radial growth for a given year using the following equation:

$$I_t = \frac{R_t}{G_t}$$

where:

I_t – is the radial growth index in a year t;

R_t – the measured value for the radial growth for the year t;

G_t – the value for the radial growth for the year t, which is determined by a regression equation (trend).

In order to determine the degree of influence of climatic conditions on the radial growth of the trees, multifactor regression analysis is applied (Fritts, 1976; Cook, Kairiukstis. 1990, Mirchev et al., 2000). It examines the influence of several independent (factor) variables (average monthly temperatures and monthly precipitation amounts) on one dependent (resultant) variable (average radial growth index). The regression model has the following general form:

$$Y_i = b_0 + b_1 x_1 + b_2 x_2 + ... + b_n x_n + E_i$$

where:

Y_i – dependent variable,

$x_{ji}\ (j = 1,2,,...n)$ – independent variables,

$b_0, b_1, b_2 ... b_n$ – parameters of the model (regression coefficients),

E_i – residual component.

The influence of the temperatures and precipitations to the tree-ring formation was described by calculations of the regression coefficients. To calculate "climate-growth" dependence, the months from October of the previous year to September of the year of annual ring formation for the period 2005-2020 were used.

Results and discussion

Climate specifics are a crucial factor that has a decisive influence on the formation of annual tree-rings of the woody plants. The town of Kardzhali belongs to thesub-Mediterranean climate region, formed under the influence of transformed tropical air masses and those of temperate latitudes (Sabev, Stanev, 1963). The area has a positive radiation balance throughout the year. The precipitation regime has an autumn-winter maximum and a summer minimum. The drought period covers the months June, July, August and September. The month with the heaviest rainfalls is December, followed by November and May. The annual amount of precipitation for the year period 1955-2017 for the town of Kardzhali is 628 mm. The average annual temperature is 18 °C. The warmest months of the year are July and August, with a slight predominance in July with an average daily temperature of 30 °C. January is the coldest month, with an average daily temperature of 6 °C (Aleksandrov et al. 2004).

The radial growth of the two species was shown in Fig. 1A. The average value for the radial growth for Austrian black pine is 3.5 mm. The annual rings varying from 0.75 mm for the year 1962 to 7.57 mm for 1955. Mean width of the Colorado spruce is 3.2 mm, ranging from 1.18 for 2011 to 5.71 for 1983. It was found out that the Austrian black pine is older – number of measured annual rings is 65 in comparison with tree-rings of the Colorado spruce which are 44. It is evident that the group of *Pinus nigra* Arn. trees were planted in the city park 20 years before (in the 1950s) the trees of *Picea pungens* Engelm., which became part of the park dendroflora in the 1970s. Judging from the biological characteristics of both species, it was claimed that the studied individuals are still at a young, juvenile age – Austrian black pine reaches the age of over 700 years, and Colorado spruce over 600 years. The calculated tree-ring sensitiveness of the dendrochronological series is relatively low for both species – 0.297 for *Pinus nigra* Arn. and 0.295 for *Picea pungens* Engelm. The explanation of that fact can be connected with the age of the trees. At a young age, coniferous tree species have a high vital energy that helps to overcome stressors of various factors, which would have a negative impact on young plants. From ecological point of view, low sensitivity in young trees can be described as a strategy for the survival of the species, which was acquired in the course of the phylogenetic development of these species during thousands of years. The high vital energy of the young Austrian black pine trees is evident from the overcoming of the deep 8-year growth depression (Fig. 1A) which lasted from the year of 1959 to 1967. The direct visual observation of the growth depression is incorporated as illustration in Fig. 1A and clearly indicates the sharp decline in the negative period of development after 1958 and the sharp recovery in 1968. Although

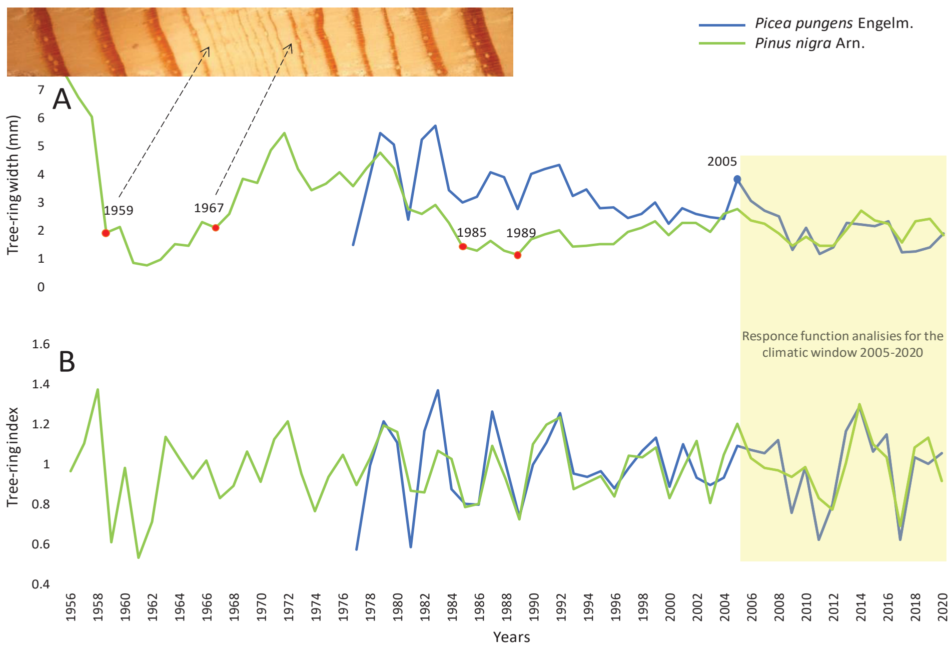

Figure 1. Tree-ring chronologies: A – row (mm) series and B – scandalized (index) chronologies of *Picea pungens* Engelm. and *Pinus nigra* Arn. *Comment: growth depression 1959-1967 in Pinus nigra Arn. is visualized by picture incorporated in graphic A.*

shorter (4 years) and not so clearly pronounced, reduction of the tree-ring increment was found for the year frame 1985-1989. After this period until 2020, Austrian black pine shows no signs of growth failure and the trees are in good condition without significant fluctuations in the radial growth. Surprisingly, in contrast with the native tree species (*Pinus nigra* Arn.), the annual increment of the introduced tree species (*Picea pungens* Engelm.) is stable for all 44 measured years in dendrochronological series and no signs of growth depressions are detected. It is interesting to note that the last 20 years mark a peak in the increase in diameter in year 2005, which correspond to the registered heavy rainfall and floods in August in Bulgaria.

The annual rings of both species show an indifferent attitude to the changing environment. The trees are in conditions of ecological tolerance, so far they have an adaptive capacity and the constant negative trend of decreasing radial growth was not evident. The analyses of the reasons for this observation were examined by application of response function (multiple regression) analysis. Indexed tree-ring chronologies (Fig. 1B) for the period 2005-2020 were used to study functional dependence of the radial growth from the temperatures and precipitations.

The correlation coefficients calculated in the regression model for the functional dependence of tree-ring formation from air temperature from October of the previous year to the September of the year of ring formation, is shown in Fig. 2. The cor-

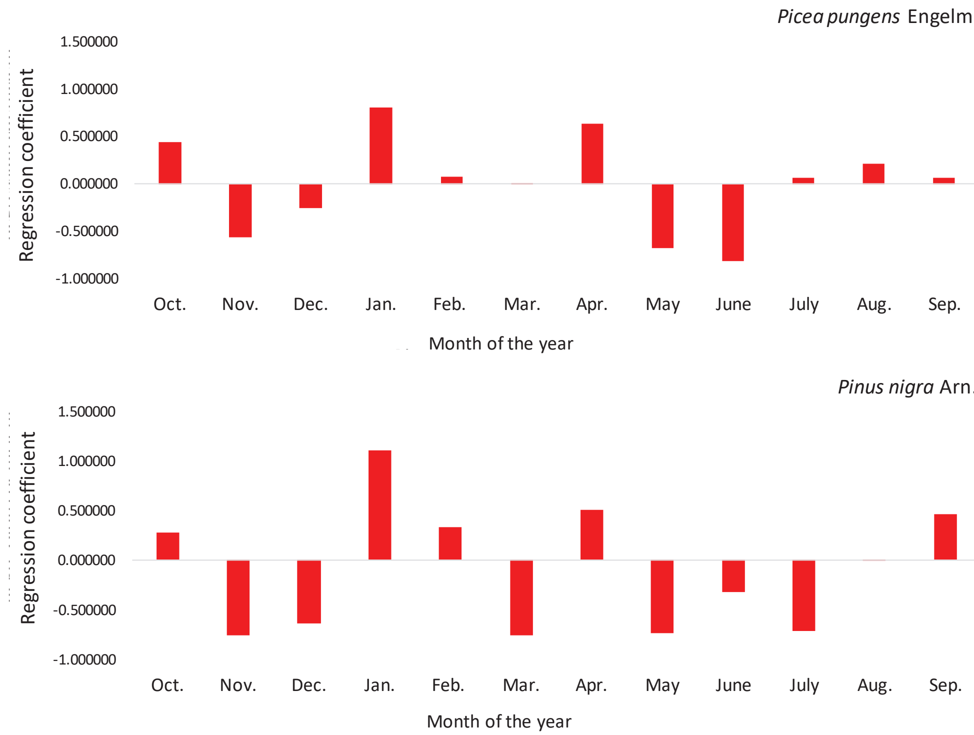

Figure 2. Response function regression coeficients for the influence of the monthly air temperatures to the tree-ring formation

relation with the high temperatures in April is positive for both tree species. The high temperatures in April create favorable conditions for starting cambial activity in the beginning of the vegetation season. The high temperatures during the months May and June definitely play a negative role in the formation of the annual rings of Colorado spruce. This fact can be explained by the circumstance that these months characterize with the most significant share in the formation of the annual rings. This is the time of formation of the widest part of the xylem, the so-called in wood anatomy earlywood (Richter at al. 2004). At high temperatures during the formation of earlywood it is possible to reach the depletion of soil moisture and to lack the necessary resources for the normal functioning of the cambium, and hence it lead to the formation of a narrow annual ring. It is noteworthy that the hot summer months of July and August, as well as September, play neither a positive nor a negative role in radial growth. For the Austrian black pine high temperatures during May, June and July suppressed formations of wide tree-rings. In contrast with the Colorado spruce, the hot September has a beneficial effect on the end of the growing season and facilitates the formation of a wide proportion of latewood as part of a complete tree-ring for the Austrian black pine. The temperatures in August play neutral role for xylem formation for *Pinus nigra* Arn. Winter temperatures are also important for the formation of annual rings.

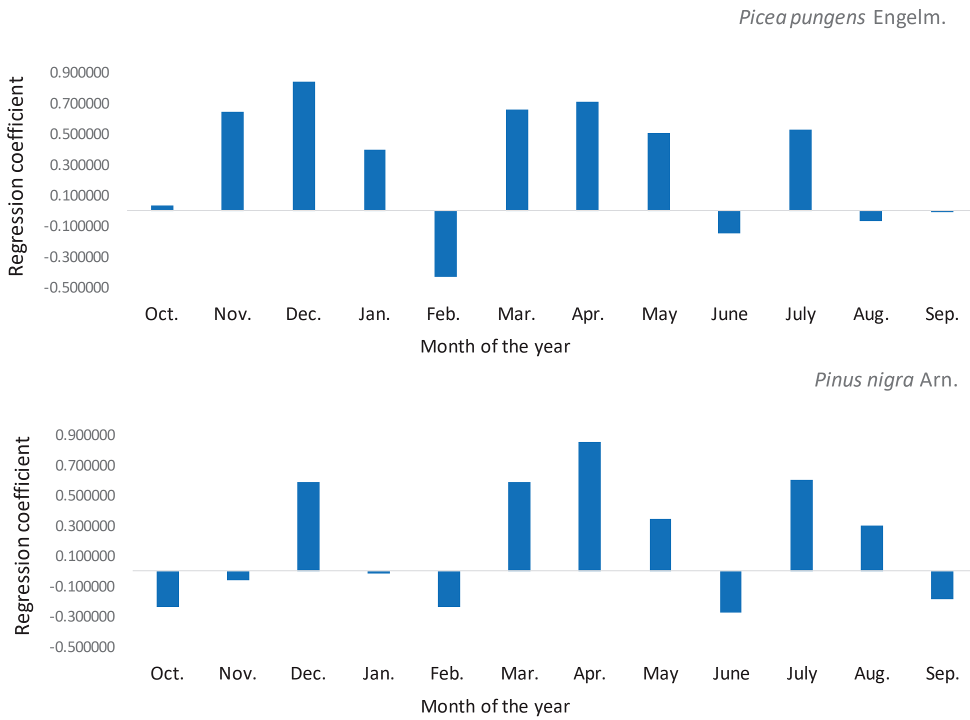

Figure 3. Response function regression coefficients for the influence of the monthly amount of precipitations to the tree-ring formation

They indirectly affect the cambial activity of woody plants because during the winter the physiological processes in trees are dormant. The winter temperatures play a crucial role in formation environmental conditions that subsequently affect the development of plants during the growing season. For example, high temperatures during the winter months do not allow the retention of snow cover, and this leads to a saturation of the soil with moisture in the winter. In the cold winter months with permanent negative temperatures, snow cover accumulates and the rapid increase of temperatures during springtime contributes to a rapid snow melting. It creates a hydrological effect of high values of surface water runoff and small values of infiltrations of water in the deep soil layers. Lack of soil moisture in the hot summers could lead to stress in the functionality of the trees in the warmest part of the year. This is an explanation for the clear positive relationship established with the high temperatures in January and February for both tree species.

Regarding precipitation, the results of the multiple regressions (Fig. 3) for Colorado spruce and Austrian black pine shows that the high rainfall in March, April and May has a strong positive effect on the formation of annual rings. It is noteworthy that in both species over-wetting in June leads to negative consequences for growth. Rainfall in July correlates positively with the ability of species to grow in diameter. The values of the regression coefficients for the second hottest month of the year August, surprisingly show that precipitation does not play a significant role in the width of the annual rings. The same trend of indifference persists in September. The positive correlation with precipitation in December can be related to the high soil moisture content that accumulates during the winter months and serves as a reserve in case of a dry last month of the winter and the spring (March, April and May).

Conclusions

Both tree species – Austrian black pine (*Pinus nigra* Arn.) and Colorado spruce (*Picea pungens* Engelm.) in the urban city park "Prostor" in the town of Kardzhali are characterized by good growing parameters and are suitable for urban greening. Long years growth depression, so called in forest sciences – forest decline, is not established. One of the main reasons for good conditions of the trees is sufficient rainfall and snowfall during the winter period and neutral reaction of these two species to the temperatures in July, August and September. A possible explanation for the absence of growth stress (last twenty years) might be the young age of the trees, which requires additional interdisciplinary investigations.

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References

Alexandrov V., Schneider,M., Koleva E. 2004. Climate variability and change in Bulgaria during the 20th century. Theor Appl Climatol 79, 133–149. https://doi.org/10.1007/s00704-004-0073-4

Cook E.R., Krusic P.J., HolmesR.L., Peters K. 2006. Program ARSTAN Ver. 44h3.

Cook E.R., Peters K. 1981. The smoothing spline: a new approach to standardizing forest interior tree-ring width series for dendroclimatic studies. Tree-Ring Bulletin 41: 45–53.

Cook E.R., Kairiukstis L.A. 1990. Methods of Dendrochronology: Applications in the Environmental Sciences. Kluwer, Dordrecht, 394 pp.

Douglass A. E. 1914. A Method of Estimating Rainfall by the Growth of Trees. Carnegie Institute of Washington, Pub. 192, 101–121.

Douglass A. E. 1928. Climate and Trees. Nature Magazine. Nature Magazine.

Fritts H. C., 1976. Tree Rings and Climate. Academic Press, London.

Holmes R. L., Adams R.K., Fritts H.C. 1986. Quality Control of Crossdating and Measuring: A Users Manual for Program COFECHA. In: Tree-Ring Chronologies of Western North America: California, eastern Oregon and northern Great Basin Laboratory of Tree-Ring Research, University of Arizona 41–19.

MEA. 2005. MA Conceptual Framework. MEA, Ecosystems and Human Well-being. Island Press, Washington, D.C. 25-36. ISBN 978-1559633901

Menconi M. E., Palazzoni L., Grohmann D. 2021. Core themes for an urban green systems thinker: A review of complexity management in provisioning cultural ecosystem services. Urban Forestry & Urban Greening 65, https://doi.org/10.1016/j.ufug.2021.127355

Mirchev S., Lyubenova M., Shikalanov A., Simeonova N. 2000. Dendrochronology (short course). Pensoft, Sofia-Moscow. (In Bulgarian).

Richter H.G., Grosser D., Heinz I., Gasson P.E. 2004. IAWA list of microscopic features for softwood identification. IAWA J. 25: 1–70.

Rinn F. 2005. TSAP-Win User Reference, Heidelberg, 91 p.

Sabev L., Stanev Sv. 1963. The climatic regions of Bulgaria and their climate. Zemizdat, Sofia, 182 p. (In Bulgarian).

Schweingruber F. H. 1996. Tree Rings and Environment. Dendroecology. Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf, Paul Haupt Publishers, Berne–Stuttgart–Vienna, 609 p.