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DIFFERENCES IN RESPONSE OF RADIAL GROWTH OF PEDUNCULATE OAK (*QUERCUS ROBUR* L.) TO CLIMATE CHANGE IN SHELTERBELT AND FOREST STAND IN THE FOREST-STEPPE ZONE OF UKRAINE

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Abstract

This paper presents an analysis of climatic factors affecting radial increment in pedunculate oak (*Quercus robur* L.) in shelterbelt and forest stand in conditions of the Left Bank Forest Steppe of Ukraine. Standard dendrochronological methods and methods of variational statistics have been used. Tree sensitivity over time was assessed in terms of Pearson's correlation strength. Two periods (1965–1990 and 1991–2016) were compared to detect features of the response of latewood, earlywood, and total rings to climate change in the shelterbelt and forest stand. The following tendency was revealed: increase in the mean annual temperature by 1.1ºC (15 %), increase in the temperature in April-August by 1.1 °C (6 %), increase in March temperature by 1.4 °C (1470%), increase in winter temperature by 1.0 °C (25 %) in 1965–1990 by comparison with 1991–2016. Mean annual precipitation increased by 20 mm (4 %), precipitation in April-August increased by 10 mm (4 %) and winter precipitation decreased by 32 mm (10 %). For the shelterbelt, the significant negative correlations between the annual and latewood index series and temperatures for April, June, the average temperatures for April-August and average annual temperatures were detected for 1965–1990. Also, a significant negative correlation between the annual index series and temperature for April was revealed. Precipitation for June significantly restricted the annual increment. At the same time for forest stand only significant negative correlations between the annual and latewood index series and precipitation for April were found. In 1991–2017 significant negative correlations between latewood and September temperatures for the shelterbelt were found. Despite greater sensitivity of the oak radial growth to changes in environmental conditions and its lower stability in the shelterbelt compared to the forest stand, the radial growth of trees surviving after a severe drought in 1975 stabilized in 2010–2017.

Key words: climate change, shelterbelt, radial increment, pedunculate oak, weather parameters

Introduction

Degradation of agro-landscapes is one of the main factors in reducing the productivity of land resources. It is caused by the long-term use of insufficiently ecological systems of agriculture, violation of optimal structural and functional organization of the territory, as well as the balance of its main stabilizing components. All this leads to a decrease in anti-erosion resistance of agricultural landscapes, deterioration of their ecological condition. Shelterbelts are an integral part of fields. Their main function is to protect the soil from water and wind erosion, increase crop yields. Where forest shelterbelts are cut down, wind erosion prevails: winds blow away dried fertile soil layer, causing dust storms. And only the rock remains in the place of weathered chernozem (Koptev 1981, Stadnik 2004, Gladun et al. 2014). It has been calculated that the ecological and economic efficiency of forested landscapes is 20–30 % higher than in open areas (Yukhnovsky 2003).

There are many publications covering problems of protective forestry and agroforestry. It is emphasized that the solution to these problems is possible when monitoring and restoring the existing forest stands and shelterbelts (Maluha 1998, Furdychko and Stadnik 2009, Stadnik 2012, Gladun et.al. 2014, Kalbarczyk et al. 2016, Maillet et al. 2017, Howat and Laroque 2019).

Shelterbelts are an important component of ecological networks. Without them it is impossible to improve the conditions for the formation and restoration of the environment, enhancement of the natural resource potential of the territory, conservation of landscape and species biodiversity, habitats, genetic resources, ways of animal migration, etc. (Yukhnovsky 2003, Maksymenko and Klieschc 2018, Maksymenko et al. 2018).

A number of works have emphasized on the impact of shelterbelts on agro-landscapes' optimization (Koptev 1981, Yukhnovsky 2003, Gladun et al. 2014), but few of them have been devoted to the health condition of shelterbelts (Vysotska et. al. 2018). At present, the state of the protected forest stands in Ukraine, their functioning and protective efficiency are not yet at the proper level.

In Ukraine, the protection of fields with shelterbelts has been a priority (Koptev 1981, Gladun et al. 2014), but the condition of these forest belts under climate warming has not been sufficiently studied. Trees in the protective forest belts are deteriorating. This is associated with a decrease in the stand resilience in the face of climate change. Consequently, monitoring of the health condition of forest shelterbelts is extremely urgent.

Radial increment is an integral parameter that is a bioindicator reflecting the tree's response to environmental changes. The loss of forest resilience in the event of an unstable ecological situation can be reflected in the radial growth variability of the trees and its constant suppression. The assumption that global climate change is the most common cause of massive forest decline is nowadays almost an alternative hypothesis. However, it is extremely relevant to identify specific mechanisms of mass forest decline (Ray et al. 2010, Ramsfield et al. 2016, Seidl et al 2017, Jactel et. al 2019,). Dendrochronological methods allow us to carry out research both in spatial and temporal aspects (Bitvinskas 1974).

Dendrochronological studies of pedunculate oak in the Left-bank forest-steppe forest stands have been carried out (Koval et al. 2017), but the variability of radial growth in shelterbelts of the region is a ‘white spot’ in the studies. Studying the dynamics of oak radial growth in shelterbelts of the Left-bank Forest Steppe will allow a better understanding of the health condition of this species in the region.

The purpose of the research was to identify the features of the response of radial increment of *Quercus robur* L. to climate changes in the shelterbelt and forest stand in the Left Bank Forest Steppe of Ukraine.

Materials and Methods

The study of radial growth of trees was carried out in 2017, in 70-year-old pedunculate oak stands in shelterbelt and forest stand growing on the territory of the Research and Production Center (Research Center) ‘Research Field’ of V.V. Dokuchaev Kharkiv National Agrarian University in the forest-steppe zone (Fig. 1). The distance between the shelterbelt and forest stand is 2 km. Cores were taken in shelterbelt (latitude: 49°54′15″ N, longitude: 36°26′54″ E) and forest stand (latitude: 49°54′42″ N, longitude: 36°27′22″ E).

The shelterbelt and forest stand consists of *Quercus robur* L. with admixtures of *Acer platanoides* and *Fraxinus excelsior* L. The shelterbelt has 5 rows of trees. The average tree diameter (DBH) is 29.2 cm in the shelterbelt, and 24.0 cm in the forest stand.

Climatic parameters (monthly air temperature and precipitation) were taken from Kharkiv weather station (latitude: 49°58′50″ N, longitude: 36°15′09″ E, altitude: 113 m a.s.l.). The climate is temperate continental. According to Kharkiv weather station, the warmest (21.0 °C) and wettest (61 mm) months are July, and the coldest is January (-5.5 °C); March (34.2 mm) is characterized by the lowest rainfall. The average temperature for the year is 8.2 °C, and precipitation sum is 552 mm. Mean annual temperature and annual precipitation, as well as same monthly parameters, were calculated for 1960–2017. Soils are chernozem, typical heavy loam.

Standard dendrochronological methods have been used (Bitvinskas 1974, Cook and Kairiukstis 1990). The cores have been taken from 20–25 trees at a height of 1.3 m from the surface using a

Fig. 1. Geographical location of experimental plots.

Pressler borer. Then all cores were air-dried.

The widths of early, late and annual increments were measured with a digital equipment HENSON up to 0.01 mm. All cores were dated using visual and graphical techniques to reveal the exact date of formation for each tree ring (Cook and Kairiukstis 1990). The proportion of latewood was calculated for 1960–2017 for cores from shelterbelt and forest stand. Tree-ring chronologies were indexed by the 3-year moving average (Bitvinskas 1974).

The development of oak in the shelterbelt and in the forest stand was investigated analyzing curves of the oak radial growth. We applied the methods of descriptive statistics and correlation analysis to study tree ring chronologies for earlywood, latewood and annual ring for 1960–2017 and correlation analysis to evaluate the relationships between ring index chronologies of oak trees and climatic parameters for 1965–1990 and 1991–2016 using software Excel 2010. Tree sensitivity over time was assessed using Pearson's correlation.

Results and Discussion

Analysis of the dynamics of the early, late and annual increment of oak trees for both experimental plots has shown their highest growth in 1960–1968. In 1969–1975 there was a decrease in growth. In 1976–1984 an increment of all wood layers increased again. In the following period 1985–2017, a gradual decrease of the radial increment was observed in the shelterbelt, while the stabilization of radial increment was observed in the forest stand (figs 2 and 3).

No significant difference was found between the width of early, late and annual wood in the shelterbelt and forest stand over the period 1960–2017. It has been found that annual oak rings were wider in the shelterbelt due to better lighting and larger nutrition area for the trees. The difference between the mean values of annual wood was 9 %, of latewood – 15 %, while no significant difference was found for earlywood (Table 1).

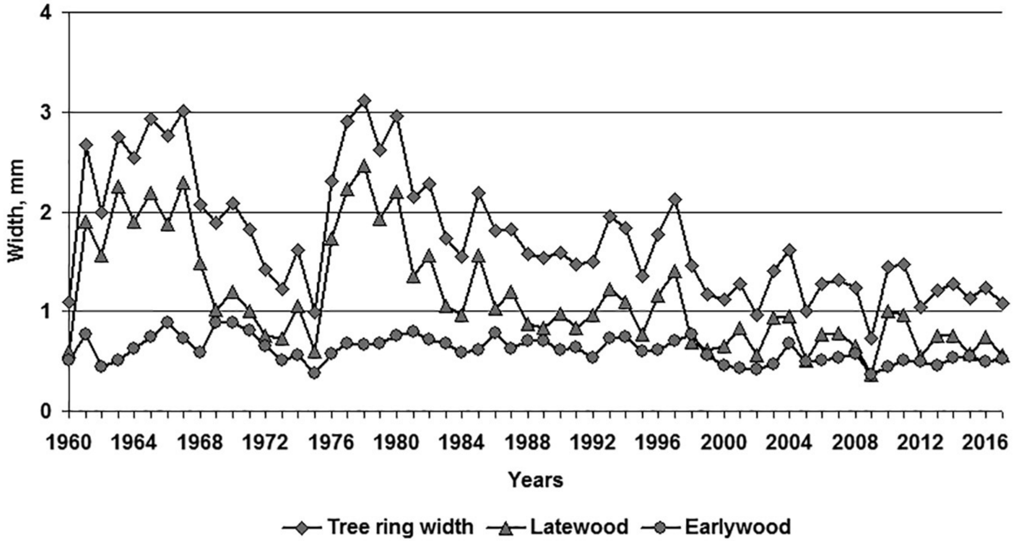

Fig. 2. Dynamics of annual, latewood and earlywood of oak trees in shelterbelt.

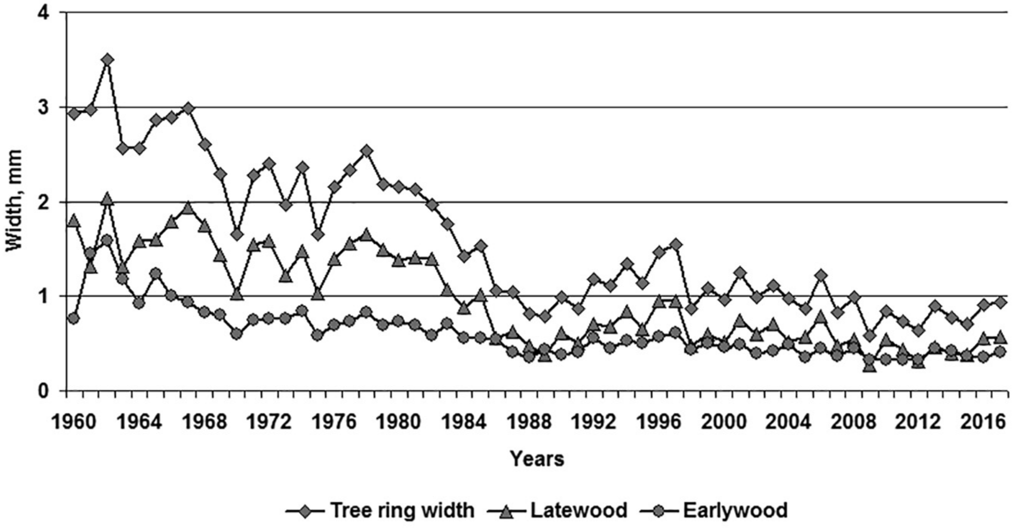

Fig. 3. Dynamics of annual, latewood and earlywood of oak trees in forest stand.

Table 1. Statistics of earlywood, latewood, and annual radial increment in forest stand and shelterbelt for 1960–2017.

Variant	Radial increment, mm ±SE	Variation coefficient, %	Significance of difference between radial increment in shelterbelt and forest stand	
			t_{fact}	$t_{0.05}$
		Annual wood		
Shelterbelt	1.75 ±0.08	35	1.24	1.96
Forest stand	1.59 ±0.10	49		
		Latewood		
Shelterbelt	1.14 ±0.07	48	1.78	1.96
Forest stand	0.97 ±0.07	51		
		Earlywood		
Shelterbelt	0.61 ±0.02	21	0.06	1.96
Forest stand	0.61 ±0.02	44		

Latewood was the most sensitive to environmental changes for both stands (see Table 1). Annual wood took the second place, and the earlywood took the third place, as evidenced by variation coefficients. The variability of types of wood is significant because it exceeds 20 % (Dospekhov 1985). This can be explained by the fact that the formation of earlywood is affected by weather conditions not only of the current year but also the previous years, while formation of latewood is influenced mainly by the conditions of the current year (Table 1).

The similarity of dynamics of increment of earlywood, latewood and annual wood for both stands was proved by the correlation analysis (Table 2). Close correlations between all types of increments have been calculated for forest stand, unlike the shelterbelt, where high correlations are observed only for latewood and annual wood. Average correlation is found for earlywood and latewood, annual wood and earlywood. This is evidenced by a large number of factors influencing the radial growth in the shelterbelt and difference in conditions for the growth of trees for both stands.

Table 2. Correlation coefficients between different types of wood for shelterbelt and forest stand, growing on the territory of the 'Research field', V. V. Dokuchayiv Kharkiv Agrarian University for the period of 1960–2017.

Type of wood	Correlation coefficient	t_{fact}	$t_{theoretical}$
Shelterbelt			
Annual and late	0.98 ±0.02	39.68	$3.39_{0.001}$
Annual and early	0.61 ±0.10	5.81	$3.39_{0.001}$
Late and early	0.46 ±0.12	3.89	$3.39_{0.001}$
Forest stand			
Annual and late	0.98 ±0.03	34.14	$3.39_{0.001}$
Annual and early	0.92 ±0.05	17.01	$3.39_{0.001}$
Late and early	0.83 ±0.08	10.76	$3.39_{0.001}$

The formation of earlywood layers is influenced by weather conditions of previous years, unlike latewood, which is formed mainly under the influence of weather conditions of the current year.

Oak latewood more fully reflects the stress conditions for tree growth than earlywood because it is more sensitive to changing environmental conditions (Amineva et al. 2014). In our research under stressful conditions in shelterbelts, where there is a higher wind speed and temperature contrasts, the correlation between earlywood and latewood is average, that is, weaker than between other types of wood mentioned in the above studies. As noted by Bitvinskas (1974), the ratio of earlywood and latewood in the annual ring is influenced by the age of the tree, its height, type of growth and location of the tree in the stand. The long-term variability of earlywood and latewood is, in most cases, influenced by a nearly identical set of meteorological conditions, determining the variability of the tree ring width as a whole. In some years, there are quite significant deviations from the 'normal' ratios of earlywood and latewood in the annual ring of the tree (i.e. the advantage of earlywood or latewood). These deviations are probably most often caused by the effects of short-term extreme changes in environmental conditions.

There were 63 % of latewood in the annual tree increment in the shelterbelt, and 60 % in the forest stand, i.e. the difference was insignificant. The percentage of latewood ranged from 44 % to 82 %. It has been confirmed that the percentage of latewood in oak decreases with age (Fig. 4).

There are three periods of oak radial increment for shelterbelt and forest stands:

- The first period (1960–1970) was characterized by synchronous growth and excess of the average width of annual rings in the forest stand by 14 %, i.e. the difference between the absolute values of radial growth was insignificant.
- The second period (1971–1975) was characterized by a sharp decrease in the oak radial increment in the shelterbelt, when it was reduced by 37 %, and this difference was significant. This was due to the arid year 1971, when a deviation from the precipitation rate was 24 %. As a result, oak growth in the shelterbelt has sharply worsened. The drought triggered a decrease in radial growth in the shelterbelt with less favorable conditions

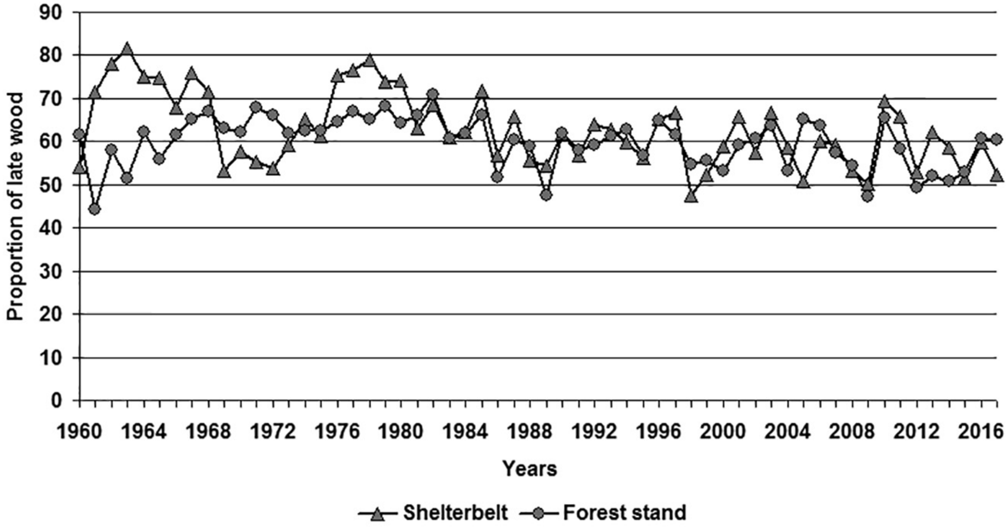

Fig. 4. Proportion of latewood in the width tree ring of oak trees in the shelterbelt and forest stand.

than in forest stand because the growth conditions for the trees in the shelterbelt were more extreme than in the forest due to higher moisture deficiency.

- The third period (1976–2017) was characterized by a 25 % increase in radial increment for the shelterbelt by comparison with the corresponding values in the forest due to severe drought in 1975 (30 % less precipitation than normal) (Fig. 4), which caused the mortality of weakened trees in the shelterbelt. Due to this the area of nutrition supply and lighting increased, causing a sharp radial growth in the shelterbelt.

Therefore, despite the fact that oak radial increment is more sensitive to changes in environmental conditions and less stable in the shelterbelt compared to the corresponding values on the control, radial growth of trees that survived the severe droughts of 1975 and 2002 stabilized in 2010–2017 (figs 5 and 6).

Years of minimum increment for both plots are 1964, 1970, 1975, 1984, 1989, 1995, 2002, 2005, 2009, 2013 and 2015. Years of maximum increment are 1967, 1974, 1978, 1985, 1997, 2006, 2010 and 2016. Growth depressions are caused by low precipitation and high temperatures. Wide annual rings formed due to favorable heat and moisture ratio (figs 4 and 5).

Radial growth indices for earlywood, latewood, and annual wood were evaluated to find the relationship between climatic factors and radial growth.

The following tendency was revealed: increase in the mean annual temperature by 1.1 ºC (15 %), increase in the temperature in April–August by 1.1 ºC (6 %), increase in March temperature by 1.4 ºC (1470 %), increase in winter temperature by 1.1 ºC (25 %) in 1965–1990 in comparison 1991–2016. Mean annual precipitation increased by 20 mm (4 %), precipitation in April–August increased by 10 mm (4 %) and winter precipitation decreased by 32 mm (10 %) in 1965–1990 in comparison to 1991–2016.

For the shelterbelt, the significant neg-

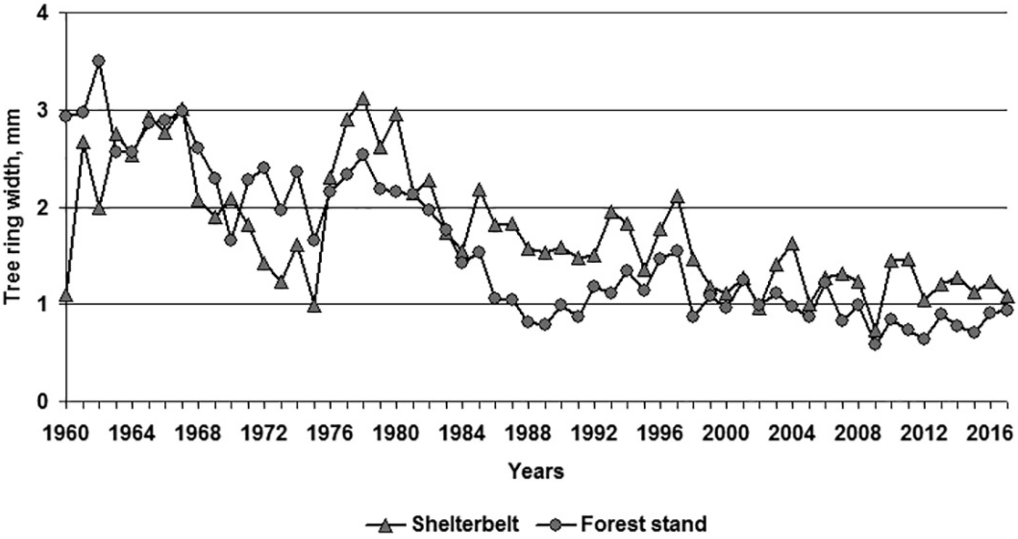

Fig. 5. Dynamics of radial growth of oak trees in shelterbelt and in forest stand.

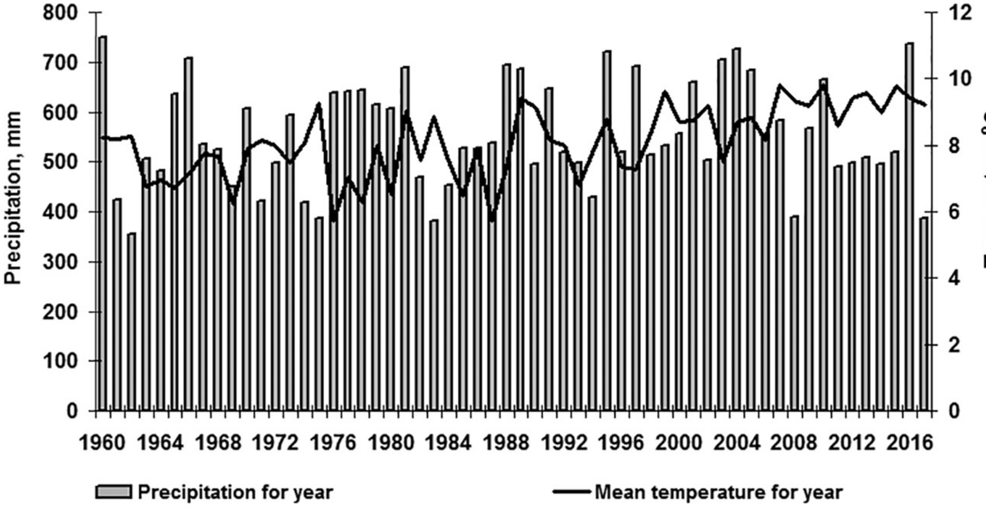

Fig. 6. Dynamics of annual precipitation and mean temperatures according to Kharkiv Weather Station.

ative correlations between annual and latewood index series and temperatures for April, June, the average temperature for April–August and average annual temperatures were detected for 1965–1990. Also, a significant negative correlation between annual index series and temperature for April was revealed. Precipitation for June significantly restricted the annual increment. At the same time for forest stand only significant negative correlations between the annual and latewood index series and precipitation for April were found (Table 3).

Table 3. Correlation analysis between the indices of radial growth and climatic parameters for two periods: 1965–1990 and 1991–2016.

Parameter	1965–1990			1991–2016		
	Annual wood	Latewood	Earlywood	Annual wood	Latewood	Earlywood
Shelterbelt						
Average temperature in April, °C	**-0.43**$_{0.05}$	**-0.43**$_{0.05}$	-0.15	-0.11	-0.15	0.10
Average temperature in May, °C	**-0.49**$_{0.05}$	-0.40	-0.41	-0.09	-0.03	-0.23
Average temperature in June, °C	**-0.67**$_{0.001}$	**-0.66**$_{0.001}$	-0.23	-0.20	-0.18	-0.17
Average temperature in September, °C	-0.20	-0.18	-0,14	-0.35	**-0.43**$_{0.05}$	0.04
Average temperature in April-August, °C	**-0.58**$_{0.01}$	**-0.59**$_{0.01}$	-0,11	-0.07	-0.,05	-0.10
Average annual temperatures, °C	**-0.44**$_{0.05}$	**-0.44**$_{0.05}$	-0,10	-0.23	-0.23	-0.09
Total precipitation in June, mm	**0.53**$_{0.01}$	0.50	0.27	0.18	0.18	0.10
Forest stand						
Average temperature in April, °C	**-0.46**$_{0.05}$	**-0.42**$_{0.05}$	-0.30	0.01	0.02	-0.06

In 1991–2016 significant negative correlations were found between latewood and September temperatures for the shelterbelt (Table 3). Despite greater sensitivity of oak radial growth to changes in environmental conditions and its lower stability in shelterbelt compared to forest stand, the radial growth of trees surviving after a severe drought in 1975 stabilized in 2010–2016.

The shelterbelt was much more sensitive to weather stress factors as compared to the forest stand because it has a greater number of significant correlations between the radial increment and climatic parameters. For the first period, a negative correlation was found between the tree ring indices of annual and latewood from one site and April, May, June, the average temperature for April–June and annual temperature from another site except for latewood and May temperature. June precipitation restricts the annual ring growth (Table 3). That is, annual and latewood were the most sensitive to changes in environmental conditions. In the forest stand the formation of annual rings and latewood was restricted by April temperatures for the first period.

In the second period, significant negative correlations were found only between latewood and September temperatures for the shelterbelt.

Previous studies of radial growth of pedunculate oak in the green zone of Kharkiv (Koval and Kostyashkin 2015) have revealed that the number of significant correlations decreased in 1988–2011 compared with 1967–1987. In the first period (1967–1987) radial growth was restricted mainly by the temperatures of the growing season and early spring, and in the second period – only by early spring. In our case, in the second period, there is also a decrease in significant correlations between radial growth and climate parameters.

Thus, it turned out that oak was more sensitive, and therefore, less resistant to weather stress in the shelterbelt. In the second period, the number of significant correlations between radial growth and climatic factors declined significantly.

Presently oak trees in shelterbelt and forest stand are adapted to climate change in the Left Bank Forest Steppe of Ukraine. This information can help guide the management of shelterbelt systems in this area.

Conclusions

It has been revealed that radial growth in the shelterbelt is more sensitive to changes in environmental conditions than in forest stand, as evidenced by poorer correlations between tree-ring chronologies of annual increment, earlywood, and latewood compared to the corresponding values for the forest stand.

The drought in 1975 (by 30 % less precipitation than normal) caused drying up of some trees in the shelterbelt and forest stand, which led to increase in the radial growth of the remained alive trees due to increased nutrition areas and improved light conditions.

During 1965–1990 the negative correlations were found between the tree ring indices of annual and latewood from one site and April, May, June, the average temperature for April–June and annual temperature from another site except for relationships for latewood and May temperature. June precipitation restricted annual rings. In the forest stand the formations of annual rings and latewood were restricted by April temperatures for the first period. In 1991–2016 significant negative correlations were found only between latewood and September temperatures for the shelterbelt. Despite greater sensitivity of oak radial growth to changes in environmental conditions and its lower stability in the shelterbelt, compared to the forest stand, the radial growth of trees surviving after severe droughts in 1975 stabilized in 2010–2017.

Presently oak trees in shelterbelt and forest stand have adapted to climate change in the Left Bank Forest Steppe of Ukraine.

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