2. ЛІСОЗНАВСТВО, ЛІСІВНИЦТВО ТА МИСЛИВСЬКЕ ГОСПОДАРСТВО

Наукові праці Лісівничої академії наук України
Proceedings of the Forestry Academy of Sciences of Ukraine

http://fasu.nltu.edu.ua
https://doi.org/10.15421/412411
Article received 2024.05.09
Article accepted 2024.10.18

ISSN 1991-606X print
ISSN 2616-5015 online
@ ✉ Correspondence author
Iryna Koval
Koval_Iryna@ukr.net
86 Hryhoriy Skovoroda st., Kharkiv, 61024, Ukraine

*UDC 630*561.24: 551.583.4*

Dendrochronological studies in beech stands of the Skolivski Beskydy National Nature Park

I. M. Koval[1], N. V. Maksymenko[2], I. M. Shpakivska[3]

The object of the study is the primary European beech forest in the Skolivski Beskydy National Nature Park. The subject of the study is the response of the radial increment of Fagus sylvatica L.*, to climate change. The paper aims to establish the relationships between the radial increment of beech and climatic factors in order to reveal the sensitivity of beech stands to climate change.*

Standard dendrochronological methods were applied. The response of the radial increment of beech was compared for two periods: 1974-1996 and 1978-2019. In the second period, the increase in temperature compared to the first period, occurred at different rates: in autumn – by 14%, in summer – by 9%, in winter – by 29%, during the calendar year – by 14%. However, against the background of a slight increase in average annual precipitation (by 2%), there were some changes in the precipitation regime in the second period compared to the first one: the precipitation increased by 6% in winter, by 11% in spring, and by 2% in autumn. In summer, on the contrary, precipitation decreased by 3%. Correlations between tree-ring chronologies of Fagus sylvatica L.*, temperatures, precipitation, and hydrothermal indicators (Selyaninov, de Martonne, Forest aridity index) showed that a decrease in the precipitation and an increase in evaporation due to a rise in air temperature in the second period made beech stands more vulnerable to the moisture regime. This is confirmed by significant correlation coefficients between radial increment and their increase in the second period. However, European beech has adapted to climate change at this stage. This is evidenced by tree-ring chronologies of early, late, and one-year-old wood, which did not show a significant decrease in the trend of the tree radial increment.*

Key words: *the reaction of the radial increment to climate change; temperature; precipitation; hydrothermal coefficients of de Martonne, Selyaninov, O_1 and O_3.; forest aridity index.*

[1] *Iryna M. Koval* – Full Member of Forestry Academy of Sciences of Ukraine, Doctor habil. (Agricultural Sciences), Senior Researcher, the G. M. Vysotsky Ukrainian Research Institute of Forestry and Forest Melioration, 86 Hryhoriy Skovoroda st., Kharkiv, 61024, Ukraine. E-mail: Koval_Iryna@ukr.net ORCID: https://orcid.org/0000-0001-6328-1418

[2] *Nadiya V. Maksymenko* – Doctor habil. (Geographical Sciences), professor, head of the Department of Environmental Monitoring and Protected Areas Management, Karazin Institute of Environmental Sciences, the V. N. Karazin Kharkiv National University, 6, Svobody st., Kharkiv, 61022, Ukraine. E-mail: nadezdav08@gmail.com ORCID: https://orcid.org/0000-0002-7921-9990

[3] *Iryna M. Shpakivska* – PhD in Biological Sciences, Senior Researcher, head of the Department of Ecosystemology, the Carpathian Ecology Institute of the National Academy of Sciences of Ukraine, 4, Kozelnytska st., Lviv-26, 79026, Ukraine. E-mail: ishpakivska@ukr.net ORCID https://orcid.org/0000-0002-5152-6083

Introduction. European beech, or common beech (*Fagus sylvatica* L.) is dominant in Europe. It grows in pure and mixed stands with conifers, whose distribution is limited mainly to the territory of the Alps and the Carpathians (Walentowski et al., 2017; Adamic et al., 2023). The main area of beech stands in Ukraine (40 % of the total area of the region [Олійник, 2008]) is concentrated in the Carpathians at an altitude of 250-1,400 m above sea level. European beech is an important species to highlight the impact of environmental constraints on European forest ecosystems as it is sensitive to climate fluctuations. Current climate change adversely affects its growth vigor due to its sensitivity to soil moisture deficits (Roibu et al., 2017) and exposure to prolonged periods of drought (Fotelli et al., 2001). The *Skolivski Beskydy* National Nature Park (NNP) was created in 1999 based on the Skoliv Forest Reserve of national significance, as well as part of the territory of the Zelemin Landscape Reserve and the Maidan Landscape Reserve, the Dubynske, Sopit, and Zhuravlyna protected tracts (Дейнека, Мілкіна, Приндак, 2006). Primeval forests have been preserved in the protected zone of the park at absolute heights of 700-1,200 m above sea level. (Король та ін., 2022).

From the Industrial Revolution to the present, the global Earth temperature has increased by 0.8°C. Mountain regions are characterized by a slightly lower increase in average annual air temperature: 0.7°C in the Ukrainian Carpathians (Адаптація до зміни клімату, 2015). Since 1970, global surface temperatures have increased faster than in any other period (Team, Lee, & Romero, 2023). The ecological consequences of climate change manifest themselves differently in individual regions depending on their geographical location, the specifics of climatic and soil conditions, the biological features of plants, their coenotic relationships, and the direction of successional processes (Стойко, 2011). The rate of climate change may outpace the ability of many biological species to adapt to the transformed conditions of the natural environment, which may affect their species composition and condition. Climate change over the past decades has significantly impacted the forest vegetation conditions of the Ukrainian Carpathians, changes in the composition of woody vegetation have resulted in some shifting of the boundaries of forest vegetation belts, which has led to a decrease in the biotic stability of certain tree species. At the same time, the area occupied by spruce decreased, while the area under beech and fir forests, on the contrary, increased (Шпарик, Криницький, Дебринюк, 2020). V.I. Komendar (Комендар, 1957), K.A. Malinovsky (Малиновський, 1980), and S.M. Stoyko (Стойко, 2009) believed that the meandering belts of spruce-beech forests are shifting upwards. It is necessary to assess the vulnerability of beech forests to the effects of climate change and their ability to adapt to such impacts. For studying the problem of adaptation of beech forests to climate change, natural forests protected in the network of the nature reserve fund are the most suitable.

The tree radial increment is a complex indicator of the condition of trees during their ontogenesis and allows revealing the reaction of stands to changes in climatic factors (Cook & Kairiukstis, 1990). The study of the layers of early, late, and one-year-old beech wood will be useful for decision-making in the field of natural resource use and environmental protection activities, and is also a direct indicator of the state of stands and their stemwood productivity (Приходько та ін., 2022). Dendroclimatic studies are based on the fundamental axiom that tree growth is a response to specific climatic conditions (Schweingruber, 1996).

Many works deal with the study of the radial increment of common beech in the Carpathian forests (Троцюк та ін., 2013; Roibu et al., 2017; Шишканинець, Мазепа, 2018; Lavnyy, Mazepa, & Shyshkanynets, 2020; Приходько та ін., 2022). An increase in the vulnerability of trees to stress factors can be expressed in an increase in the significant impact of temperature and precipitation on the radial increment of trees (Коваль, 2023). Studying the dynamics of the radial increment of beech stands under Climate Change is important for assessing their condition and productivity. Changes in temperature and precipitation (Diaz, Bradley, & Eischeid, 1989) and the speed of these changes are among the most important factors in climate change (Gavrilov et al., 2019). Complex analysis of temperature and precipitation resembles better their combined effects on tree growth. Parameters representing a mathematical coefficient/ratio of the precipitation (or air humidity values) and temperature are known as drought indices. Hence, such indices are important not only as indicators of plant growth but can also be considered important indicators of climate change (Arora, 2002).

Objects and methods. The object of the study is the primary forest of common beech (*Fagus sylvatica* L.) in the *Skolivski Beskydy* National Nature Park (NPP) The subject of the study is the reaction of the radial increment of common beech to climate change. The aim of the article is to find the relationships between the radial increment of beech and climatic factors to reveal the sensitivity of beech stands to climate change.

According to physical and geographical zoning, the park is located within the Verkhnyodnistrovsky and Skolivskyi Beskydy districts, occupying the northern macroslopes of the latter with absolute heights ranging from 600 to 1,200 m. The climate of the park is mild, moderately warm and humid. Winters are with frequent thaws at temperatures from 0 to +5 °C. The duration of the growing season is 180 days. The average temperature in January is -4.5– -6 °C, in July it is +15.6-18.0 °C with a maximum of +30 °C and a minimum of -31 °C. 800-1,100 mm of precipitation falls here per year. The average depth of the snow cover is 39 cm. The soil cover is dominated by brown mountain forest very gravelly soils. On the territory of the park, the remains of natural highly productive and biologically stable stands have been preserved –

age-old pure beech forests of natural origin, which largely reflect the diversity of the Beskydy forest cover (Національний природний парк…, 2024).

To better understand how the radial increment of high-altitude beech forest responded to climate change, we collected 11 cores in the beech stand of the Skolivski Beskydy NPP at an altitude of 800 m above sea level (Fig. 1).

Fig. 1. Site of collection of common beech wood cores in the “Skolivski Beskydy” NNP

Generally accepted dendrochronological methods were used (Битвинскас, 1974; Cook & Kairiukstis, 1990; Schweingruber, 1996). The tree cores were packed in paper containers and labeled, that is, the samples were prepared for transportation to the laboratory. The next step was to measure the earlywood and latewood layers of the trees using HENSON equipment. Dating was carried out to establish the calendar date of the formation of each annual ring. Standardization, i.e. elimination of the age (biological trend) was calculated using a three-year sliding scale (Битвинскас, 1974). Pointer years were selected and the difference between temperatures and precipitation was analyzed for the periods of 1974-1996 and 1997-2019. A pointer year is considered to be a year in which the radial increment of trees is 40 % less for most of the sampled trees than in the previous four years (Jetschke, Maaten, & Maaten-Theunissen, 2019).

Then a correlation analysis (Атраментова, Утєвська, 2007) was conducted between the indices of early, late, and one-year-old wood and climatic factors (temperature, precipitation, and hydrothermal coefficients) for the same periods from June of the previous year to August of the current year.

A well-known aridity parameter is the De Martonne aridity index (DM). This index can be calculated for different time scales such as months, seasons, and years. The DM index is used worldwide to determine the dry/humid climate conditions of a region or regions (Baltas, 2007; Croitoru et al., 2013; Gavrilov et al., 2019). The annual and monthly values of the aridity index DM, IaDM and ImDM, can be calculated by equations 1 and 2, respectively:

$$IaDM = \frac{Pa}{Ta} + C' \qquad (1)$$

$$ImDM = \frac{Pm}{Tm} + C' \qquad (2)$$

where *Pa* and *Pm* are the annual and monthly precipitation, *Ta* and *Tm* are the average yearly and monthly air temperatures, and $C' = 10$ºC is the De Martonne constant.

De Martonne’s classification of climate dryness is given in Table 1 with 7 types of climate dryness. Humidity increases with increasing values *IaDM* and *ImDM*, Using formulas 1 and 2, the de Martonne index series were created for the calendar year and the April-September period.

Table 1. **Classification of de Martonne aridity index**

Types of Climate	*IaDM* value
Arid	$IaDM < 10$
Semi-arid	$10 \le IaDM < 20$
Mediterranean	$20 \le IaDM < 24$
Semi-humid	$24 \le IaDM < 28$
Humid	$28 \le IaDM < 35$
Very humid	$35 \le IaDM < 55$
Extremely humid	$IaDM \ge 55$

Forestry Aridity Index (FAI) is defined as (Führer et al., 2011):

$$FAI = Cg \times T_{VII\text{-}VIII} / (P_{V\text{-}VII} + P_{VII\text{-}VIII}), \qquad (3)$$

where $T_{VII–VIII}$ is the average temperature in July and August in ºC, $P_{V\text{-}VII}$ is the sum of precipitation from May to July and $P_{VII\text{-}VIII}$ is the precipitation for July–August, in mm and Cg is 100 mm/ºC is a constant. By introducing a constant Cg with dimension (Alley, 1984), *FAI* lost its dimension and became a “true” index, i.e., a dimensionless number. FAI can be a perfect tool to represent climatic conditions during annual forest growth, which is especially important for those involved in forestry and agriculture (Gavrilov et al., 2019).

In contrast to the De Martonne aridity index, humidity increases with decreasing FAI value and vice versa.

Table 2. **Meteorological features of forest climatic categories (Führer, Horvath, Jagodics, Machon, & Szabados, 2011)**

Values *FAI*	Forest climatic categories
FAI < 4.75	Beech climate
4.75 ≤ *FAI* < 6.00	Hornbeam-oak climate
6.00 ≤ *FAI* < 7.25	The sessile oak/Turkey oak climate
FAI > 7.25	Forest-steppe climate

Using equation (3), we supplemented the database with *FAI* time series for the Lviv weather station.

The G. T. Selyaninov Hydrothermal Index (HTI) is the sum of precipitation during the period when the average daily air temperature is above +10°C divided by the sum of active temperatures during the same period when the temperature exceeded +10°C, reduced by a factor of 10. It is calculated according to the formula:

$$HTI = R / 0.1\ \Sigma T, \quad (4)$$

where R is the amount of precipitation during the period with a temperature above 10°C;

$\sum T > 10°C$ – the sum of active temperatures above 10°C.

This indicator has an advantage over others and characterizes the profitable part of the water balance (precipitation) and the unproductive moisture consumption (evaporation from the soil surface, and vegetation). HTI is a reliable indicator of humidity in areas characterized by a uniform type of annual precipitation. In addition, it is objective and works in a fairly wide range of combinations of temperature and precipitation (Свириденко, Бабіч, Киричок, 2004).

To characterize environmental conditions, we also used complex climatic indicator – the ratio of air temperature and precipitation for the hydrological year, which begins in October of the previous year and ends in September of the current year (Битвинскас, 1974):

$$O_1 = t_o\ 100 / V_o, \quad (5)$$

where O_1 is the hydrothermal coefficient; t_o is the temperature for a hydrological year (ºC), V_o is the amount of precipitation (mm) for the same period.

As a norm (WMO Guidelines on the Calculation of Climate Normals, 2017) we took the average width of early, late, and one-year-old wood and the average temperature and sum precipitation for 1960-2019.

Results. When comparing temperatures and precipitation for the periods 1974-1996 and 1997-2019, it was found that in the second period compared to the first one, the average annual temperature increased almost by 1.2 °C (14.4 %), in autumn – by 1.06°C (14.3 %), and in summer – by 1.7 (9.4 %). Temperatures rose most noticeably in winter and spring – by 0.7 °C (29 %) and 1.25 °C (14.3 %), respectively. In the second period, precipitation increased by 11.7 mm, i.e. by 1.5 %. These changes according to the seasons of the year proved to be uneven. In the 1997-2019 period, compared to the 1974-1996 period, the amount of precipitation increased in winter by 9.3 mm (6.4 %), in spring by 21.7 mm (11.3 %), and in autumn by 4.1 mm (2.4 %). In summer, on the contrary, precipitation decreased by 8.7 mm (3.2 %) during this period (Fig. 2).

The pointer years of minimum (1964, 1972, 1977, 1982, 1990, 1998, 2008, 2014, 2018) and maximum tree increment (1973, 1976, 1989, 1999, 2009) were identified (Fig. 3).

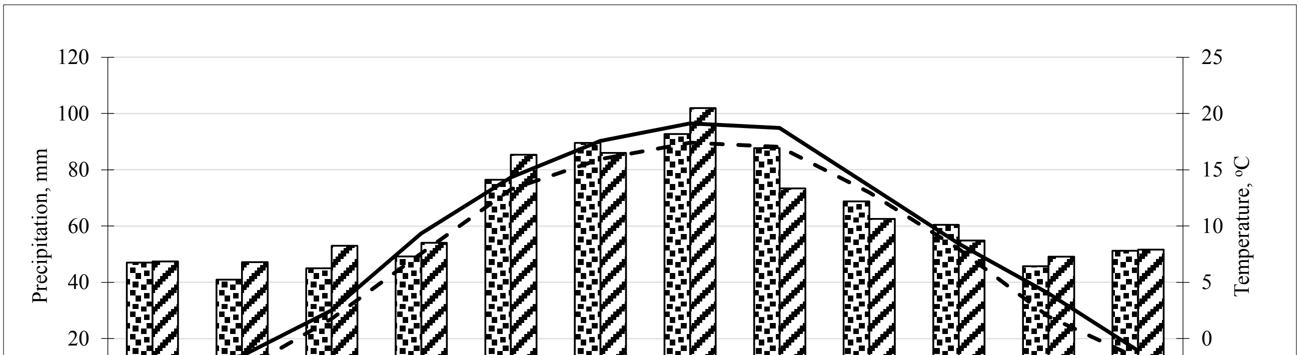

Fig. 2. Climatogram according to the data of the Lviv weather station

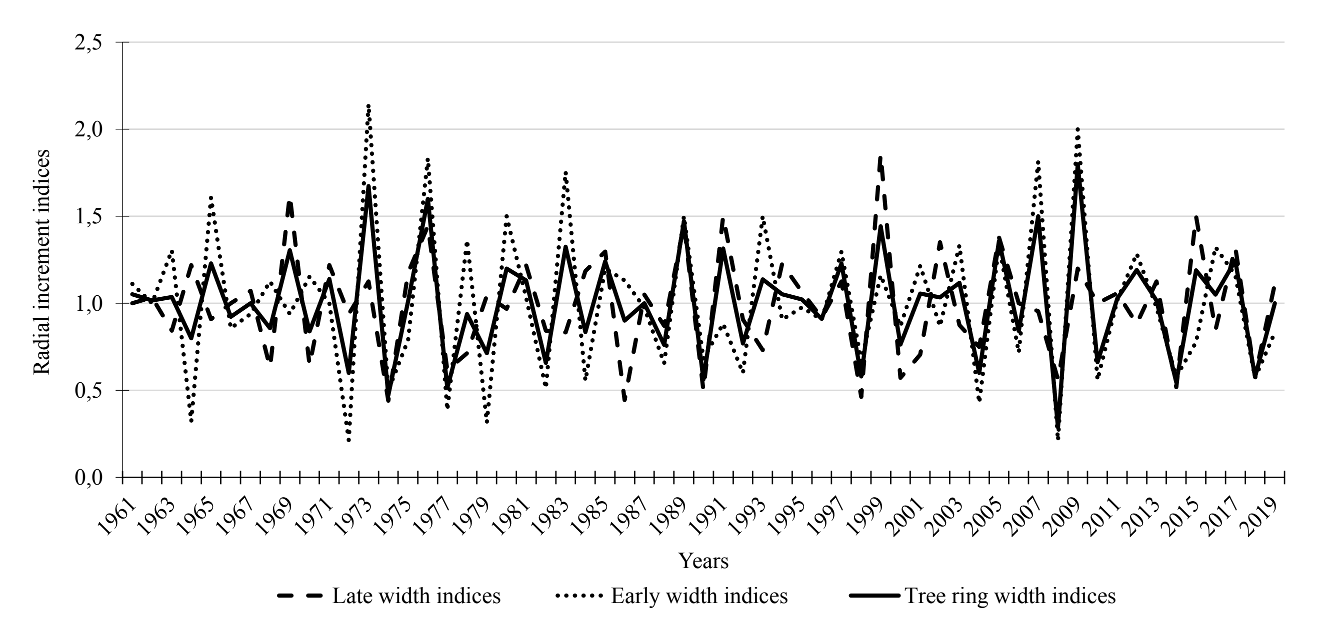

Fig. 3. Dynamics of late width indices, early width indices and tree ring width indices

Pointer years of minimal growth are characterized by high temperatures during the growing season (the temperature deviation from the norm during April – August was 14-15 %) and abnormally warm or extremely cold winters (the average temperature deviation for the period from December of the previous year to February of the current year was from 40 up to 107%). Precipitation limited the radial increment of beech to a lesser extent. However, in 1986 growth depression was caused by a lack of precipitation during the growing season and in winter when it affects moisture accumulation in the soil (36 mm, or 35 % below normal). In the years of maximum tree growth, an optimal heat/humidity ratio was evaluated.

Pointer years of minimal growth are characterized by high temperatures during the growing season (the temperature deviation from the norm during April-August was 14-15 %) and abnormally warm or extremely cold winters (the average temperature deviation for the period from December of the previous year to February of the current year was from 40 up to 107 %). Precipitation limited the radial increment of beech to a lesser extent, but in 1986, growth depression was caused by a lack of the precipitation during the growing season and in winter, when precipitation affects moisture accumulation in the soil (the deviation from the norm was 36 mm, which was 35%). The years of maximum tree growth were characterized by an optimal ratio of heat and humidity.

In the 1974-1996 period, the temperatures of the previous year and the April temperatures of the current year mainly had a positive effect on the radial increment of the European beech, in the 1997-2019 period, this effect either weakened or became negative. In the first period, the temperatures of May-August were mainly detrimental to growth, except for July temperatures, but in the second period, this effect became mostly positive. The negative impact of the temperatures of the cold period (from November of the previous year to March of the current year) somewhat weakened in the second period. For the first period, a significant positive influence of temperatures in August of the previous year ($R=0.45\pm0.20$, $t_{0.05}=2.31$) and April of the current year ($R=0.43\pm0{,}20$ $t_{0.05}=2.18$) was observed only for early wood (Fig. 4).

Correlation analysis between indices of radial increment and precipitation shows that in the periods of 1974-1996 and 1997-2019, precipitation in June-August of the previous year had a positive effect on the radial increment of beech. In the first period, a significant positive impact of July precipitation on latewood was found ($R=0.47\pm0.22$, $t_{0.05}=2.50$), in the second period, a significant positive effect of precipitation in the previous year on latewood was also found but this influence moved a month earlier – to June ($R=0.42\pm0.18$, $t_{0.05}=2.22$). The impact of precipitation from November of the previous year to March of the current year slightly weakened in the second period. Both periods are characterized by a negative effect of precipitation on growth in the summer months. A significant negative impact of August precipitation on annual wood in the first period was confirmed ($R=-0.49\pm0.23$, $t_{0.05}=-2.62$). In the second period, precipitation began to limit growth a month earlier – significant negative correlations between July precipitation and late and early wood were calculated ($R=0.53\pm0.17$, $t_{0.05}=-2.99$ and $R=0.42\pm0.17$, $t_{0.05}=-2.21$) (Fig. 5).

Correlation analysis was carried out between indices of early, late, and one-year-old wood, and G. T. Selyaninov HTI in the 1974-1996 period was 1.8, and in the 1997-2019 period it decreased to 1.6. Correlations between indices of radial increment and HTI showed that a decrease in precipitation and an increase in evaporation in the second period led to the fact that beech stands became more vulnerable to the moisture regime, as evidenced by significant negative correlations between late and one-year-old wood indices in the second period. For the calendar year, no significant relationships were found between the de Martonne index and the early, late, and one-year-old wood indices. However, for the period 1997-2019, negative average relationships were calculated for late and early wood. The forest aridity index showed an increase in the vulnerability of beech forests to the ratio of temperature and moisture in the second period (Table 3).

Hydrothermal indices O_1 and O_3 according to Bitvinskas (Битвинскас, 1974) showed insignificant correlations between the tree ring index series and these indices for both periods. Correlation analysis between indices of late, early, and annual wood showed that the research area belongs to the forest climate category – beech climate (see Table 2). In the second period, positive average relationships were found between the indexes of late and one-year-old wood, on the one hand, and the index of forest aridity, on the other hand.

Table 3. **Correlation coefficients between indices of tree rings, early and late wood, and hydrothermal coefficients**

Types of wood	Hydrothermal coefficients	
	G. T. Selyaninov HTI	
	1974-1996	1997-2019
Latewood	-0.33	**-0.42***
Earlywood	-0.25	0.00
Tree ring	-0.41	-0.35
		-0.45*
	Hydrothermal coefficient of de Martonne for April–September	
Latewood	-0.33	**-0.43***
Earlywood	-0.27	-0.37
Tree ring	**-0.42***	**-0.46***
	Forestry Aridity Index	
Latewood	0.21	**0,62***
Eearlywood	0.13	0.29
Tree ring	0.22	**0.47***

Note: * – significance at the 0.05 level

a) 1974-1996

b) 1997-2019

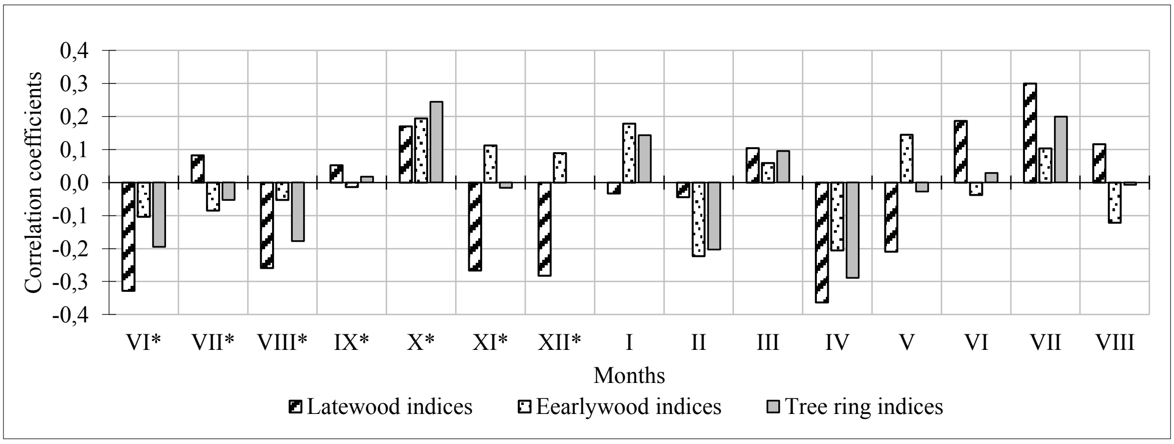

Fig. 4. Correlation coefficients between indices of early, late and one-year-old beech wood and temperatures for the periods of 1974-1996 and 1997-2019. Note: * – months of the previous year.

a) 1974-1996

b) 1997-2019

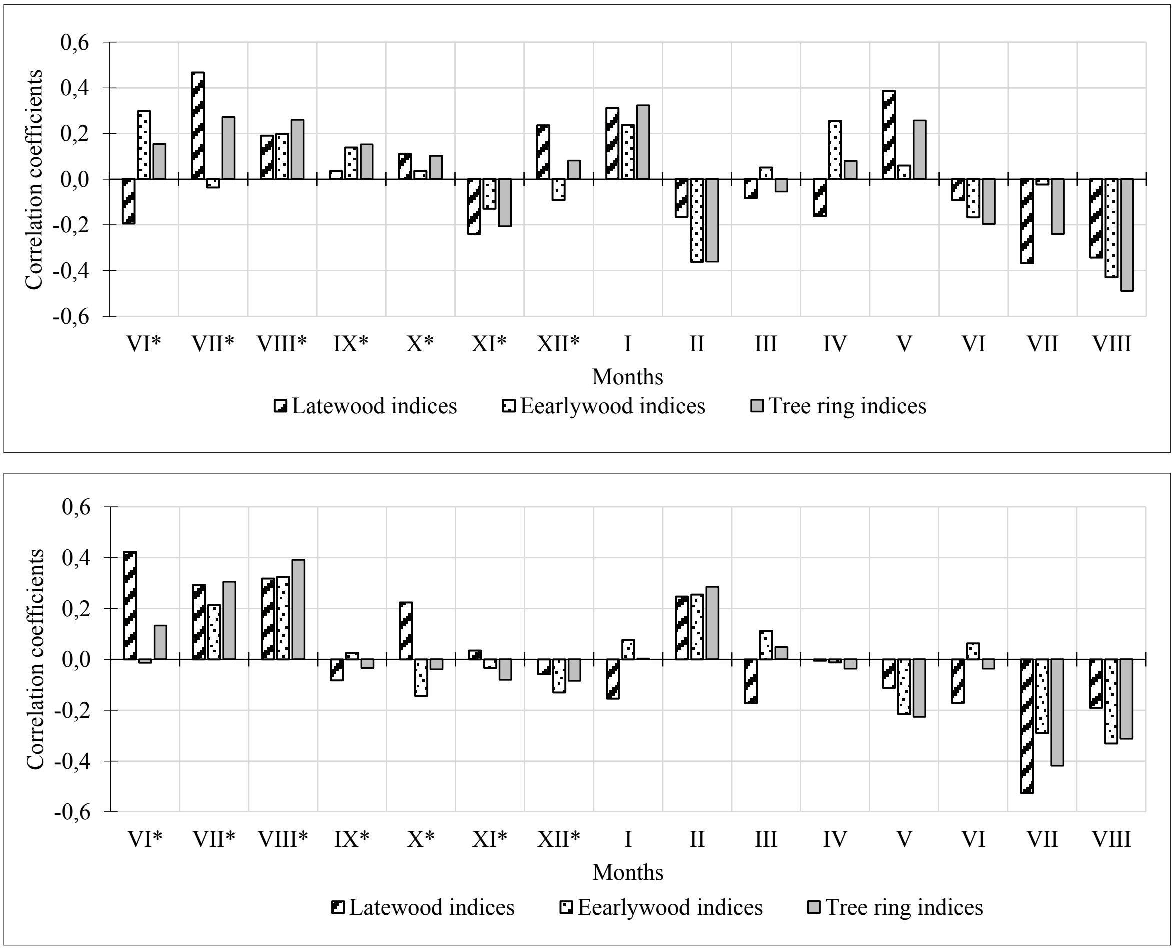

Fig. 5. Correlation analysis between indices of early, late and one-year-old beech wood and precipitation for the periods of 1974-1996 and 1997-2019. Note: * – months of the previous year.

Discussion. In pure middle-aged beech stands of the Ukrainian Carpathians, which grow in optimal conditions for beech, for the period 1992-2013, high correlations of the radial increment of trees with a complex of climatic indicators during the growing season (precipitation, temperature and air humidity, and moisture deficit) were found. In middle-aged beech stands, the radial increment is most significantly affected by air humidity and temperature, while moisture deficit and precipitation are insignificant (Шишканинець, Мазепа, 2018).

Our research established for the 1974-1996 period a significant positive effect of temperatures in August of the previous year and April of the current year on the formation of layers of early wood. No significant correlation coefficients between temperatures and growth indices were found for the 1997-2019 period. In the first period, a significant positive effect of July precipitation on latewood was found, in the second period, June temperatures of the previous year significantly affected *correlation coefficients* for latewood. A significant negative impact of August precipitation on one-year-old wood in the first period of August was confirmed. In the second period, precipitation began to limit growth a month earlier compared to the first period – in July.

Use of hydrothermal coefficients for dendroclimatic analysis showed that the sensitivity of late and one-year-old wood increased in the 1987-2019 period compared to the 1974-1986 period, as evidenced by significant correlation coefficients for late and one-year-old wood in the second period. It is important to consider the effect of changes in the ratio of heat and moisture on tree growth. In the second period, the increase in temperature compared to the first period occurred at a different rate: in autumn – by 14 %, in summer – by 9 %, in winter by 29 %, during the calendar year – by 14 %. At the same time, against the background of a slight increase in the average annual precipitation (by 1.5 %), there were some changes in the precipitation regime (the amount of the precipitation increased in winter by 6 %, in spring months by 11 %, in autumn by 2 %. However, in summer, on the contrary – precipitation decreased by 3 %.

Dendroclimatic studies of common beech in Romania found that the radial increment of trees was mainly limited by summer temperatures, the amount of precipitation in April-May, and droughts in April-June (Roibu et al., 2017).

An international group of researchers from Slovenia, the Czech Republic, and Romania found that in the Carpathians beech has better radial increment with more precipitation in July and slower growth with higher average and maximum temperatures in June of the current year. Beech also shows a negative correlation between radial increment and temperature in summer. Despite the diversity of beech populations, the future survival of beech and other temperate tree species is uncertain because the rate, uniformity and intensity of climate change vary from place to place. Beech populations at the border of the species' range have great adaptive potential, and their stability contributes to the stability of forests. Above-average rainfall in June and July had a positive impact on annual rings (Adamic et al., 2023).

A study of old-growth European beech forests in Italy found that the drought of the previous summer was the main factor limiting their growth (Piovesan et al., 2005). Our studies showed that in the years 1974-1996, temperatures and precipitation from June-October of the previous year mainly had a positive effect on radial increment of trees, but in the following years 1997-2019, not only the positive influence of temperatures on growth decreased, but also the dependence of growth on summer precipitation increased. In northern Serbia, it was found that significant positive temperature trends were not sufficient to cause any trends in annual ring width indices of common oak (*Quercus robur*) trees. The response of the annual wood indices of Scots oak changed only in response to the precipitation trend, which remained constant during the study period, and not in response to the temperature trend. That is, it turned out that climate change in response to the increase in temperature did not significantly affect forest vegetation in the study areas (Gavrilov et al., 2019).

The effects of drought on the radial increment of beech have been reported in various regions of Europe, However, the studies have not confirmed any significant response of European beech to climatic variations in the Carpathian region, which has shown high plasticity (Dittmar, Zech, & Elling, 2003).

Based on an extensive network of European dendrochronological series of beech, it was possible to build an ecological-geographical model of ring width variability in Italy (Piovesan et al., 2005). Dendroecological studies reveal the importance of tree-ring networks in defining bioclimatic zones and forest types (Dittmar, Zech, & Elling, 2003; Piovesan et al., 2005).

F. sylvatica appears to require increased temperature to be compensated by a significant increase in summer precipitation to maintain viability. Our results (2017) are consisted with those of Mette et al. (2013) who concluded that *F. sylvatica* growth is not currently critically limited by drought in this region.

Conclusions. 1. In the 1997-2019 period, the increase in temperature, compared to the 1974-1996 period, occurred at different rates: in autumn – by 14 %, in summer – by 9 %, in winter by 29 %, during the calendar year – by 14 %. At the same time, against the background of a slight increase in average annual precipitation (by 1.5 %), there were some changes in the precipitation regime (the amount of precipitation increased in winter – by 6 %, in spring months – by 11 %, in autumn – by 2 %. But in summer, on the contrary – there was a decrease in precipitation by 3 %.

2. Correlations between tree-ring chronologies of *Fagus sylvatica* L., temperatures, precipitation, and hydrothermal indices (G. T. Selyaninov HTI, de Martonne, forest aridity index) showed that the decrease in the precipitation and increase in evaporation due to air temperature in the second period led to the fact that the beech stands became more vulnerable to the moisture regime. However, European beech was able to adapt to climate change at this stage. This is evidenced by tree-ring chronologies of early, late and one-year-old wood, which did not show a significant decrease in the trend of the tree radial increment.

References

Adamič, P. C., Levanič, T., Hanzu, M., Čater, M. (2023). Growth Response of European Beech (*Fagus sylvatica* L.) and Silver Fir (*Abies alba* Mill.) to Climate Factors along the Carpathian Massive. *Forests*, *14*(7), 1318. https://doi.org/10.3390/f14071318

Alley, W. J. (1984). The Palmer Drought Severity Index: Limitations and Assumptions. *Journal of Applied Meteorology and Climatology, 23*(7), 1100-1109. https://doi.org/10.1175/1520-0450(1984)023<1100:TPDSIL>2.0.CO;2

Arora, V. K. (2002). The use of the aridity index to assess climate change effect on annual runoff. *Journal of Hydrology, 265,* 164-177. Retrieved from https://imedea.uib-csic.es/master/cambioglobal/Modulo_II_cod101604/Modulo_2_03/Puigdefabregas/Arora.pdf

Baltas, E. (2007). Spatial distribution of climatic indices in northern Greece. *Meteorological applications, 14,* 69-78. https://doi.org/10.1002/met.7

Cook, E. R., & Kairiukstis, L. A. (1990). *Methods of Dendrochronology. Applications in the Environmental Sciences*. Dordrecht: Kluwer International Institute for Applied Systems Analysis. Academic Publishers. http://dx.doi.org/10.1007/978-94-015-7879-0

Croitoru, A. E., Piticar, A., Imbroane, A. M., & Burada, D. C. (2013). Spatiotemporal distribution of aridity indices based on temperature and precipitation in the extra-Carpathian regions of Romania. *Theoretical and Applied Climatology, 112,* 597-607. https://doi.org/10.1007/s00704-012-0755-2

Diaz, H. F., Bradley, R., & Eischeid, J. K. (1989). Precipitation fluctuation over global land areas since the late 1800s. *Journal of Geophysical Research, 94,* 1195-1210. Retrieved from http://www.geo.umass.edu/faculty/bradley/diaz1989.pdf

Dittmar, C., Zech, W., & Elling, W. (2003). Growth variations of Common beech (*Fagus sylvatica* L.) under different climatic and environmental conditions in Europe – a dendroecological study. *Forest Ecology and Management*, *173*(1-3), 1-3. https://doi.org/10.1016/S0378-1127(01)00816-7

Fotelli, N.M., Geßler, A., Peuke, A.D., & Rennenberg, H (2001). Drought affects the competitive interaction between Fagus sylvatica seedlings and an early successional species, Rubus fruticosus: responses of growth, water status and δ13C composition. *New Phytologist*, *151*(2), 427-435. https://doi.org/10.1046/j.1469-8137.2001.00186.x

Führer, E., Horvath, L., Jagodics, A., Machon, A., & Szabados, I. (2011). Application of new aridity index in Hungarian forestry practice. *Quarterly Journal of the Hungarian Meteorological Service, 115*(3), 205-216. Retrieved from: https://www.met.hu/downloads.php?fn=/metadmin/newspaper/2012/04/115-3-5-fuhrer.pdf

Gavrilov, M.B., An, W., Xu, C., Radaković, M.G., Hao, Q., Yang, F., Guo, Z., Perić, Z., Gavrilov, G., & Marković, S.B. (2019). Independent Aridity and Drought Pieces of Evidence Based on Meteorological Data and Tree Ring Data in Southeast Banat, Vojvodina, Serbia. *Atmosphere*, *10*(10), 586. https://doi.org/10.3390/atmos10100586

Jetschke, G., Maaten, E., & Maaten-Theunissen, M. (2019). Towards the extremes: A critical analysis of pointer year detection methods. *Dendrochronologia, 53*, 55-62. https://doi.org/10.1016/j.dendro.2018.11.004

Lavnyy, V., Mazepa, V.G., & Shyshkanynets, I.F. (2020). Radial Increment of Beech (*Fagus Sylvatica* L.) in the Ukrainian Carpathans. *Forestry ideas*, *26*(2), 394-403. Retrieved from: https://forestry-ideas.info/issues/issues_Download.php?download=375

Mette, T., Dolos, K., Meinardus, C., Bräuning, A., Reineking, B., Blaschke, M., … Wellstein, C. (2013). Climatic turning point for beech and oak under climate change in Central Europe. *Ecosphere, 4*(12), 1-19. https://doi.org/10.1890/ES13-00115.1

Piovesan, G., Biondi, F., Bernabei, M., Filippo, A., & Schirone, B. (2005). Spatial and altitudinal bioclimatic zones of the Italian peninsula identified from a beech (*Fagus sylvatica* L.) tree-ring network. *Acta Oecologica*, *27*(3), 197-210. https://doi.org/10.1016/j.actao.2005.01.001

Roibu, C., Popa, I., Kirchhefer, Jo., Kirchhefer, A.Jo., & Palaghianu, C. (2017). Growth responses to climate in a tree-ring network of European beech (*Fagus sylvatica* L.) from the eastern limit of its natural distribution area. *Dendrochronologia*, *42*, 104-116. https://doi.org/10.1016/j.dendro.2017.02.003

Schweingruber, F.H. (1996). *Tree Rings and Environment-Dendrochronology*. Switzerland, Berne: Paul Haup.

Team, H., Lee, J., & Romero, J. (2023). Summary for Policymakers. In: H. Lee (Ed), *Climate Change 2023: Synthesis Report.* Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 1-34. IPCC, Geneva, Switzerland. https://doi.org/10.59327/IPCC/AR6-9789291691647.001

Walentowski, H., Falk, W., Mette, T., Kunz, J., Bräuning, A., Meinardus, C… Leuschner, C. (2017). Assessing Future Suitability of Tree Species under Climate Change by Multiple Methods: A Case Study in Southern Germany. *Annals of Forest Research*, 60, 101-126. https://doi.org/10.15287/afr.2016.789

WMO *Guidelines on the Calculation of Climate Normals* (2017). Retrieved from: https://library.wmo.int/viewer/55797/download?file=1203_en.pdf&type=pdf&navigator=1

Адаптація до зміни клімату (2015). Карпатський Інститут Розвитку. Агентство сприяння сталому розвитку Карпатського регіону. Форза. [Adaptation to Climate Change (2015). Carpathian Development Institute, Agency for Promotion of Sustainable Development of the Carpathian Region "Forza". Retrieved from https://forza.org.ua/sites/default/files/adaptation_climate_change_brochure_ua_screen_final.pdf] (in Ukrainian)

Атраментова, Л.О., Утєвська, О.М. (2007). *Статистичні методи в біології.* Харків: ХНУ імені В.Н. Каразіна. [Atramentova, L.O., & Utevska, O.M. (2007). *Statistical methods in biology*. Kharkiv: V.N. Karazin Kharkiv National University] (in Ukrainian)

Битвинскас, Т.Т. (1974). *Дендроклиматические исследования*. Ленинград: Гидрометеоиздат. [Bitvinskas, T.T. (1974). *Dendroclimatic research*. Leningrad: Gidrometeoizdat] (in Russian)

Дейнека, А.М., Мілкіна, Л.І., Приндак, В.П. (2006). *Ліси Національного природного парку «Сколівські Бескиди»*, Львів: Сполом. [Deineka, A.M., Milkina, L.I., & Pryndak, V.P. (2006). Forests *of the National Nature Park "Skolivski Beskydy"*. Lviv: Spolom] (in Ukrainian)

Коваль, І.М. (2023). *Дендрохронологічні засади оцінювання соснових і дубових деревостанів України*. Харків: Мачулін. [Koval, I.M. (2023). *Dendrochronological principles of assessment of pine and oak stands of Ukraine*, Kharkiv: Machulin] (in Ukrainian)

Комендар, В.І. (1957). До питання про динаміку рослинних поясів у Східних Карпатах, *Український ботанічний журнал, 14*, 15-25. [Komendar, V.I. (1957). To the questions about dynamic of plant belts in the Eastern Carpathians. *Ukrainian Botanical Journal, 14*(4), 15-25] (in Ukrainian)

Король, М., Токар, О., Густі, М., Портах, С., Нагоряк, В., Приндак, В., Земан, В., Крамарець, В. (2022). Структура природних насаджень заповідних територій Українських Карпат та оцінка стовбурового запасу вуглецю. *Наукові праці Лісівничої академії наук України, 24*, 143-152. [Korol, M., Tokar, O., Gusti, M., Portakh, S., Nagornyak, B., Pryndak, V., Zeman, V., & Kramarets, V. (2022). The structure and stem carbon of natural forest stands in the protected territories of the Ukrainian Carpathians. *Proceedings of the Forestry Academy of Sciences of Ukraine*, *24*, 143-152. https://doi.org/https://doi.org/10.15421/412213] (in Ukrainian)

Малиновський, К.А. (1980). *Рослинність високогір'я Українських Карпат*. Київ: Наукова думка [Malinovsky, K.A. (1980). *Vegetation of the highlands of the Ukrainian Carpathians.* Kyiv: Scientific opinion] (in Ukrainian)

Національний природний парк – Сколівські Бескиди (2024). [Skolivski Beskydy National Nature Park (2024). Retrieved from: http://skole.org.ua/] (in Ukrainian)

Олійник, В.С. (2008). *Водоохоронно-захисна роль гірських лісів Українських Карпат, її антропогенні зміни та шляхи оптимізації*: автореф. дис. д-ра с.-г. наук: 06.03.03. Львів, НЛТУ України [Oliynyk, V.S. (2008). Water protection and protection role of mountain forests of the Ukrainian Carpathians, its anthropogenic changes and ways of optimization. (Doctoral dissertation, Ukrainian National Forestry University, Lviv, Ukraine). Retrieved from http://www.disslib.org/vodookhoronno-zakhysna-rol-hirskykh-lisiv-ukrayinskykh-karpat-yiyi-antropohenni-zminy.html] (in Ukrainian)

Приходько, Н.Ф., Парпан, Т.В., Голубчак, О.І., Приходько, М.М., Гудима, В.М. (2022). Радіальні прирости деревостанів рекреаційно-оздоровчих лісів Придністровського Передкарпаття (Івано-Франківська область). *Науковий вісник НЛТУ України*, *32*(5), 42-49. [Prykhodko, N.F., Parpan, T.V., Holubchak, O.I., Prykhodko, M.M., Hudyma, V.M., & Pasternak, P.S. Radial growth of forest stands of recreational and health-improving forests of Prydnistrovya Subcarpathian region (Ivano-Frankivsk region). *Scientific Bulletin of Ukrainian National Forestry University*, *32*(5), 42-49. https://doi.org/10.36930/40320506] (in Ukrainian)

Свириденко, В.Є., Бабіч, О.Г., Киричок, Л.С. (2004). *Лісівництво*. Київ: Арістей. [Svyridenko, V.E., Babich, O.G., & Kyrychok, L.S. (2004). *Forestry*. Kyiv: Aristei] (in Ukrainian)

Стойко, С.М. (2009). Потенційні екологічні наслідки глобального потепління клімату в лісових формаціях Українських Карпат. *Науковий вісник НЛТУ України, 15*, 214-224. [Stoyko, S.M. (2009). Potential ecological consequences of global climate warming in forest ecosystems of Ukrainian Carpathians. *Scientific Bulletin of Ukrainian National Forestry University*, *15*, 214-224. Retrieved from: https://cyberleninka.ru/article/n/potentsiyni-ekologichni-naslidki-globalnogo-poteplinnya-klimatu-v-lisovih-formatsiyah-ukrayinskih-karpat] (in Ukrainian)

Стойко, С. (2011). Вплив глобальної зміни клімату на лісові формації Карпат. *Наукові праці Лісівничої академії наук України, 9,* 21-29. [Stojko, S. (2011). Global climate changes impact on the forest ecosystems in the Carpathians. *Proceedings of the Forestry Academy of Sciences of Ukraine*, *9,* 21-29. Retrieved from: http://fasu.nltu.edu.ua/index.php/nplanu/article/view/360] (in Ukrainian)

Троцюк, В.І., Миклуш, С.І., Коммармот, Б.М., Хобі, М.Л. (2013). Особливості росту за діаметром дерев букового пралісу. *Науковий вісник НЛТУ України*, *23*(1), 62-68. [Trotsiuk, V.I., Myklush, S.I., Commarmot, B.M., & Hobi, M.L. (2013). Peculiarities of DBH grows increment of the trees in the primeval beech forest. *Scientific bulletin of Ukrainian National Forestry University*, *23*(1), 62-68. Retrieved from: https://forestry-ideas.info/issues/issues_Download.php?download=375] (in Ukrainian)

Шишканинець, І.Ф., Мазепа, В.Г. (2018). Вплив клімату на радіальний приріст бука в середньовікових деревостанах у верхів'ї басейну річки Латориця. *Лісівництво і агролісомеліорація*, *133*, 112-118. [Shyshkanynets, I.F., & Mazepa, V.G. (2018). Influence of climate on the radial increment of beech in the middle-aged stands in upper reaches of the Latorytsya river basin. *Forestry and Forest Melioration*, *133*, 112-118. https://doi.org/10.33220/1026-3365.133.2018.112] (in Ukrainian)

Шпарик, Ю.С., Криницький, Г.Т., Дебринюк, Ю.М. (2020). Тенденції динаміки типів лісорослинних умов і породного складу деревостанів Українських Карпат у зв'язку зі змінами клімату. *Наукові праці Лісівничої Академії наук України, 20*, 82-92. [Shparyk, Y.S., Krynytskyy, H.T., & Debryniuk, Iu.M. (2020). Trends of dynamics in the site conditions types and species composition of the forest stands in the Ukrainian Carpathians caused by climate changes. *Proceedings of the Forestry Academy of Sciences of Ukraine, 20*, 82-92. https://doi.org/10.15421/412008] (in Ukrainian)

Дендрохронологічні дослідження в букових насадженнях НПП «Сколівські Бескиди»

І.М. Коваль[1], Н.В. Максименко[2], І.М. Шпаківська[3]

Об'єкт дослідження – праліси бука звичайного (*Fagus sylvatica* L.) в Національному природному парку «Сколівські Бескиди». Предмет дослідження – реакція радіального приросту бука звичайного на зміну клімату. Мета роботи полягала у вста-

[1] *Коваль Ірина Михайлівна* – академік Лісівничої академії наук України, доктор сільськогосподарських наук, старший науковий співробітник, провідний науковий співробітник сектору екології лісу відділу лісівництва та економіки лісового господарства. Український науково-дослідний інститут лісового господарства та агролісомеліорації ім. Г.М. Висоцького, вул. Григорія Сковороди, 86, м. Харків, 61024, Україна. E-mail: Koval_Iryna@ukr.net ORCID https://orcid.org/0000-0001-6328-1418

[2] *Максименко Надія Василівна* – доктор географічних наук, професор, завідувач кафедри екологічного моніторингу і заповідної справи. Навчально-науковий інститут екології Харківського національного університету імені В.Н. Каразіна, майдан Свободи, 6, м. Харків, 61022, Україна. E-mail: nadezdav08@gmail.com; maksymenko@karazin.ua ORCID https://orcid.org/0000-0002-7921-9990

[3] *Шпаківська Ірина Миронівна* – кандидат біологічних наук, старший науковий співробітник, завідувач відділу екосистемології, Інститут екології Карпат НАН України, вул. Козельницька, 4, м. Львів-26, 79026, Україна. E-mail: ishpakivska@ukr.net ORCID https://orcid.org/0000-0002-5152-6083

новленні взаємозв'язків між радіальним приростом бука та кліматичними чинниками, щоб виявити чутливість букових деревостанів до зміни клімату.

Застосовано стандартні дендрохронологічні методики. Під час здійснення дендрокліматичного аналізу використано місячні суми опадів, середньомісячні температури і гідротермічні коефіцієнти де Мартонне, Селянинова, O_1 та O_3, індекс аридності лісів. Здійснено порівняння реакції радіального приросту бука звичайного для двох періодів: 1974-1986 та 1987-2019 рр. У другому періоді збільшення температури, порівняно з першим, відбувалося з різною швидкістю за сезонами: восени – на 14%, влітку – на 9%, взимку – на 29%, упродовж календарного року – на 14%. Поряд з цим, на тлі незначного збільшення середньорічних опадів (на 2%) відбулися деякі зміни в режимі опадів у другому періоді у порівнянні з першим: кількість опадів збільшилася взимку на 6%, навесні – на 11%, восени – на 2%. Влітку навпаки – відбулося зменшення кількості опадів на 3%.

Виявлено реперні роки мінімального (1964, 1972, 1977, 1982, 1990, 1998, 2008, 2014, 2018 рр.) та максимального приросту дерев (1973, 1976, 1989, 1999, 2009 рр.). Реперні роки мінімального приросту характеризуються високими температурами упродовж вегетаційного періоду (відхилення температур від норми упродовж квітня-серпня становило 14-15%), та аномально теплими, або надзвичайно холодними зимами (відхилення середніх температур за період з грудня попереднього по лютий поточного року складало від 40 до 107%). Опади меншою мірою обмежували радіальний приріст бука, але у 1986 р. депресію приросту викликав дефіцит опадів упродовж вегетаційного періоду та взимку, коли опади впливають на вологонагромадження в ґрунті (відхилення від норми становили 36 мм, що склало 35%). Роки максимального приросту дерев характеризувалися оптимальним співвідношенням тепла та вологи.

Кореляційні зв'язки між деревно-кільцевими хронологіями *Fagus sylvatica* L., температурами, опадами та гідротермічними показниками свідчать про те, що зменшення кількості опадів та збільшення випаровуваності завдяки підвищенню температури повітря у другому періоді призвели до того, що букові насадження стали більш уразливими до режиму зволоження. Це підтверджує кількість значущих коефіцієнтів кореляції між радіальним приростом і кліматичними чинниками, яка збільшилася у другому періоді.

Водночас бук європейський наразі зміг адаптуватися до зміни клімату. Про це свідчать деревно-кільцеві хронології ранньої, пізньої та річної деревини, які не виявили значного зменшення в тренді радіального приросту дерев.

Ключові слова: реакція радіального приросту до зміни клімату; температура; опади; гідротермічні коефіцієнти де Мартонне, Селянинова, O_1 та O_3; індекс аридності лісів.