

# Response of Japanese Larch (*Larix leptolepis* Gord) Radial Growth to Climate Change in the Left Bank Forest-Steppe, Ukraine

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Article Details: Received: 2025-01-17 | Accepted: 2025-03-10 | Available online: 2025-05-31



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The research presents the response of Japanese larch (*Larix leptolepis* Gord) radial growth to climate change in the conditions of the forest-steppe of Ukraine in the Arboretum planting at the State Biotechnological University. The article develops local-tree chronologies of early, late and annual wood, considering three periods: 1979–1993, 1994–2008, and 2009–2022. The authors emphasize that the sensitivity of the radial growth of trees to climate variations increased in the third period, as evidenced by the increase in the number of significant correlation coefficients between index tree-ring chronologies and climatic factors (temperatures and precipitation), as well as hydrothermal coefficients ( $O_1$ ,  $O_3$  and the Standardized Precipitation Index (SPI)). This indicates the weakening of the plantation because of temperature increase. Early wood turned out to be the most sensitive to climate variations. The radial increment trend stabilized in 2020–2022.

**Keywords:** Japanese larch radial increment; temperature; precipitation, hydrothermal coefficients; arboretum of the State Biotechnological University

## 1 Introduction

In Ukraine, Japanese larch (*Larix leptolepis* Gord) is an introduced species and a promising species for plantation forestry. In Ukraine, mixed stands with a predominance of larch significantly prevail – 73.2 and 70.3% in area and stem wood stock, respectively (Debrinyuk, & Belelya, 2019). Plantations located outside the species' range represent natural experiments for assessing the resilience of trees to climate variability. Climate change is exacerbating drought-related stress on forest ecosystems. Currently, in the context of climate change, an important issue arises regarding the adaptation of Japanese larch to climate change, which is intensifying and cannot be stopped. In recent decades, this has caused many adverse consequences for forest ecosystems in Europe. The most important consequences of climate change in the Central and Eastern European region include: increasing frequency of extreme temperatures, decreasing summer

precipitation, more frequent floods in winter, rising water temperatures, as well as increasing risk of forest fires and decreasing forest resilience. High temperatures and drought promote the development of diseases and pests, including invasive species, increase the risk of fires and accelerate the process of soil mineralization (Meshkova et al., 2019). Due to climate change, the species composition and types of forests will undergo significant changes. The ecological optima of tree species may shift to the northeast (Shvidenko et al., 2017).

It is important to establish the adaptive capacity of Japanese larch to climate change, that is, to increase or decrease the stability, vitality and productivity of forest ecosystems.

Most studies of Japanese larch have been conducted for the Carpathians, Polesia and the Western forest-steppe, which is why it is so important to study *Larix leptolepis* Gord in the Left-Bank Forest-Steppe. The radial growth of trees is an integral indicator that reflects their state

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during ontogenesis (Cook, & Kairiukstis, 1990; Danek & Chuchro, 2019; Koval & Maksymenko, 2020). Therefore, it is relevant to study the response of the radial growth of Japanese larch to climate change.

Larch plantations are widespread in Ukraine mainly in the West, but in Eastern and Central Ukraine its plantations also show high productivity and stability. A number of scientists studied Japanese larch in the Carpathians, Polesia, Western forest-steppe and Left Bank forest-steppe (Fuchylo et al., 2018; Los et al., 2018; Debrinyuk & Belelya, 2019).

The purpose of the article is to determine the response of Japanese larch radial growth to climate change conditions in the plantation of the Arboretum at the State Biotechnological University, located in the Left Bank forest-steppe.

## 2 Materials and Methods

### 2.1 Research Object

The Arboretum at the State Biotechnological University is an object of the nature reserve fund of national importance in the Kharkiv region, which was created in the spring of 1972. Two-year-old seedlings of Japanese larch were obtained from the forestry of the Lviv Forestry Institute in 1973 (Ostapenko & Sytnik, 2011). The climate is temperate continental with unstable humidity. The average annual air temperature is +6.5 °C with fluctuations from +38 to -35 °C. The average annual precipitation is 520 mm with fluctuations from 330 to 740 mm. According to soil and climatic conditions, this is the southern part of the Left Bank forest-steppe. The type of forest-vegetation conditions is fresh loam. Soils are typical chernozems.

Cores in the larch plantation were collected in June 2024 (Fig. 1).

### 2.2 Methods

The authors applied standard dendrochronological and dendroclimatic methods in this research (Cook & Kairiukstis, 1990). Cores were taken from 11 trees. Local tree chronologies for late, early, and annual wood were created from individual tree-ring chronologies. Indices of chronologies were obtained by smoothing with a 3-year sliding scale (Bitvinskas, 1974).

For dendroclimatic analysis, correlation analysis was applied between the indices of early, late, and annual wood on the one hand, and temperatures and precipitation for the hydrological year on the other hand. Moreover, for correlation analysis between index chronologies and climatic factors, the research used

the average, minimum, maximum temperatures and precipitation amounts for the hydrological year, relative humidity and precipitation amounts for April-August, for winter period – hydrothermal coefficients (de Marton's drought index (DM), Seljanin's hydrothermal coefficient, Standardized Precipitation Index (SPI), Forestry Aridity Index (FAI), hydrothermal coefficients  $O_1$  and  $O_3$  (Bitvinskas, 1974; Keyantash, 2023; Gavrillov et al., 2019; Milentijević et al., 2018).

A correlation analysis (Atramentova, & Utevska, 2007) was conducted between the indices of early, late, and annual wood and climatic factors (temperature, precipitation, and hydrothermal coefficients (formulas 1–7)) 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 any given region or regions (Milentijević et al., 2018; Gavrillov et al., 2019). The annual and monthly values of the aridity index DM, laDM and ImDM, can be represented by formulas 1 and 2, respectively:

$$laDM = \frac{Pa}{Ta + C'} \quad (1)$$

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

where:  $Pa$  and  $Pm$  – annual and monthly precipitation ( $t \cdot ha^{-1}$ );  $Tm$  and  $Tm$  – the average annual and monthly air temperatures;  $C' = 10$  °C is the De Martonne constant

Forestry Aridity Index (FAI) is defined as (Führer et al., 2011), see formula 3:

$$FAI = C_g \frac{T_{VII-VIII}}{(P_{V-VII} + P_{VII-VIII})} \quad (3)$$

where:  $T_{VII-VIII}$  – the average temperature in July and August (°C);  $P_{V-VII}$  – the sum of precipitation from May to July;  $P_{VII-VIII}$  – the sum of precipitation for July–August (mm);  $C_g = 100$   $mm \cdot ^\circ C^{-1}$  – a constant

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

The Standardized Precipitation Index (SPI) is defined as the standardized anomaly of the precipitation (Keyantash et al., 2025).

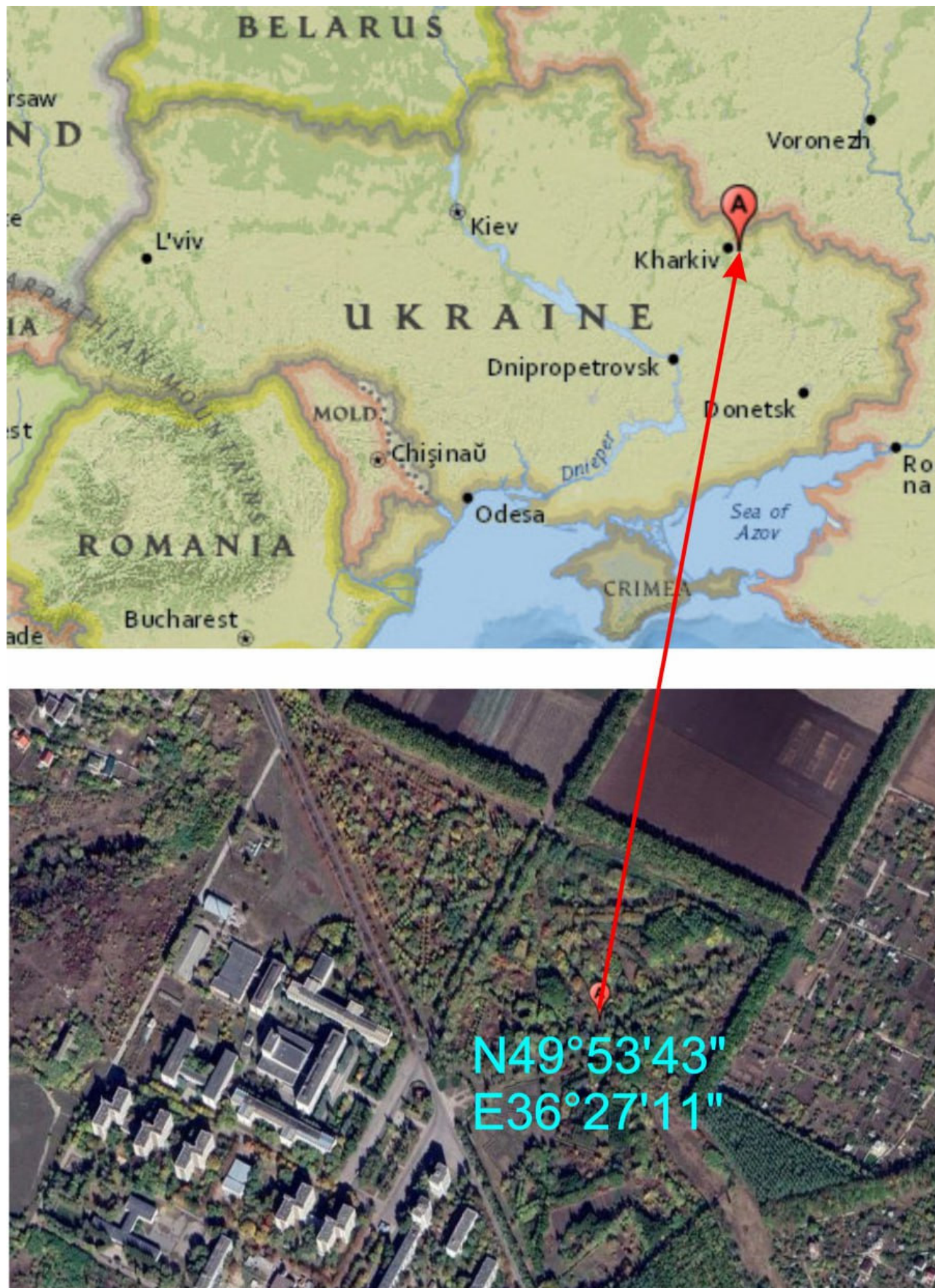


Figure 1 Sampling location

Formula 4:

$$SPI = \frac{P - P^*}{\sigma_p} \quad (4)$$

where:  $P$  – precipitation;  $P^*$  – mean precipitation;  
 $\sigma_p$  – standard deviation of precipitation

The hydrothermal moisture coefficient of G.T. Selyaninova (GTK) 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 (Milentijević et al., 2018), see formula 5:

$$GTK = \frac{R}{0.1 \sum T} \quad (5)$$

where:  $R$  – 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

To characterize environmental conditions, we used complex climatic indicators – 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 (Bitvinskas, 1974):

$$O_1 = \frac{t_0 \cdot 100}{V_0} \quad (6)$$

where:  $O_1$  – the hydrothermal coefficient;  $t_0$  – the temperature for a hydrological year (°C);  
 $V_0$  – the amount of precipitation (mm) for the same period

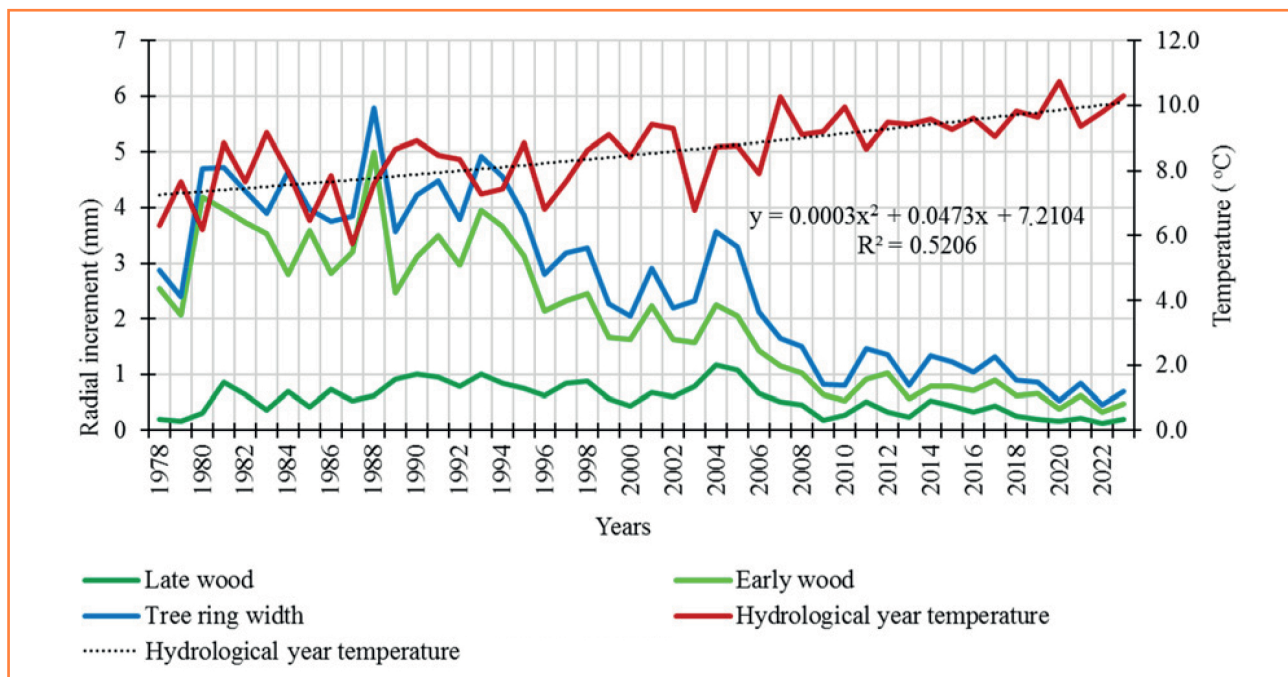
T.T. Bitvinskas found out that high results are obtained by assessing the impact of climatic factors on the growth of plantations over four years, which reflects a complex hydrothermal indicator  $O_3$  (Bitvinskas, 1974):

$$O_3 = \frac{(V_3 + 2V_2 + 3V_1 + 4V_0) \times (t_3 + 2t_2 + 3t_1 + 4t_0) \times t_0}{10,000} \quad (7)$$

where:  $V$  – precipitation for the hydrological year;  
 $t$  – average annual temperature for the same period: indices for 0, 1, 2, 3 – years (current, previous, and others)

### 3 Results and Discussion

Three periods of plantation development were established: 1978–1993 – the period of maximum radial growth of Japanese larch, 1994–2008 – the period of gradual decrease in radial growth, and 2009–2023 – the period of rapid decrease in radial growth. At the same time, during 2020–2023, the growth trend was not at the same level, that is, no decrease in growth was observed. Similarly, there was a rapid increase in temperature during the hydrological year. Thus, in the first period, the average values of the temperature of the hydrological year were 7.7, in the second – 8.5, and in the third – 9.8 °C (Fig. 2).



**Figure 2** Dynamics of tree-ring chronologies of early, late, and annual wood and temperature of the hydrological year



**Figure 3** Correlation analysis between tree-ring chronologies of early, late, and annual wood and precipitation  
 \* – months of the previous year; \*\* – significance at the 0.05 level

Correlation analysis between tree-ring chronologies of early, late, and annual wood and temperatures for the period from June of the previous year to August of the current year has shown that in the first period in the first half of winter, the effect of temperatures on growth was mainly positive, while in the second half of this period – negative. In the second period, winter warming had a positive effect on all types of wood. In the third period, a further increase in winter temperatures had a negative effect on growth. The greatest positive effect of early spring temperatures (March) on growth was also found in the second period. April and May temperatures mainly had a negative effect on growth during all periods. In June, temperatures negatively affected the growth. Moreover, it was the strongest in the third period. Positive effect of July and August temperatures on the radial growth of trees gradually decreased during all three periods. Temperatures during June–September of the previous year had a more negative impact on the radial growth of trees in the second period compared to the first, and in the third period, this impact was again mostly positive (Fig. 3).

The spring–summer season is a period of moisture consumption, and the autumn–winter period (from November of the previous year to February of the current one) is a period of moisture accumulation. Correlation analysis showed that the worst conditions for moisture accumulation were observed in the third period. During June–September of the previous year, in the first period, there was a negative effect of precipitation on growth, while in the following 2<sup>nd</sup> and 3<sup>rd</sup> periods this effect was positive. The research confirmed that in 1994–2008, precipitation had a significantly negative effect on tree-ring chronologies of all wood species. March precipitation

in the first and second periods had a positive effect on growth, and in the third period this effect became negative. April precipitation significantly negatively affected growth in the first period, in the second period this effect weakened. June precipitation mainly had a positive effect on the radial growth of larch in all three periods (Fig. 4).

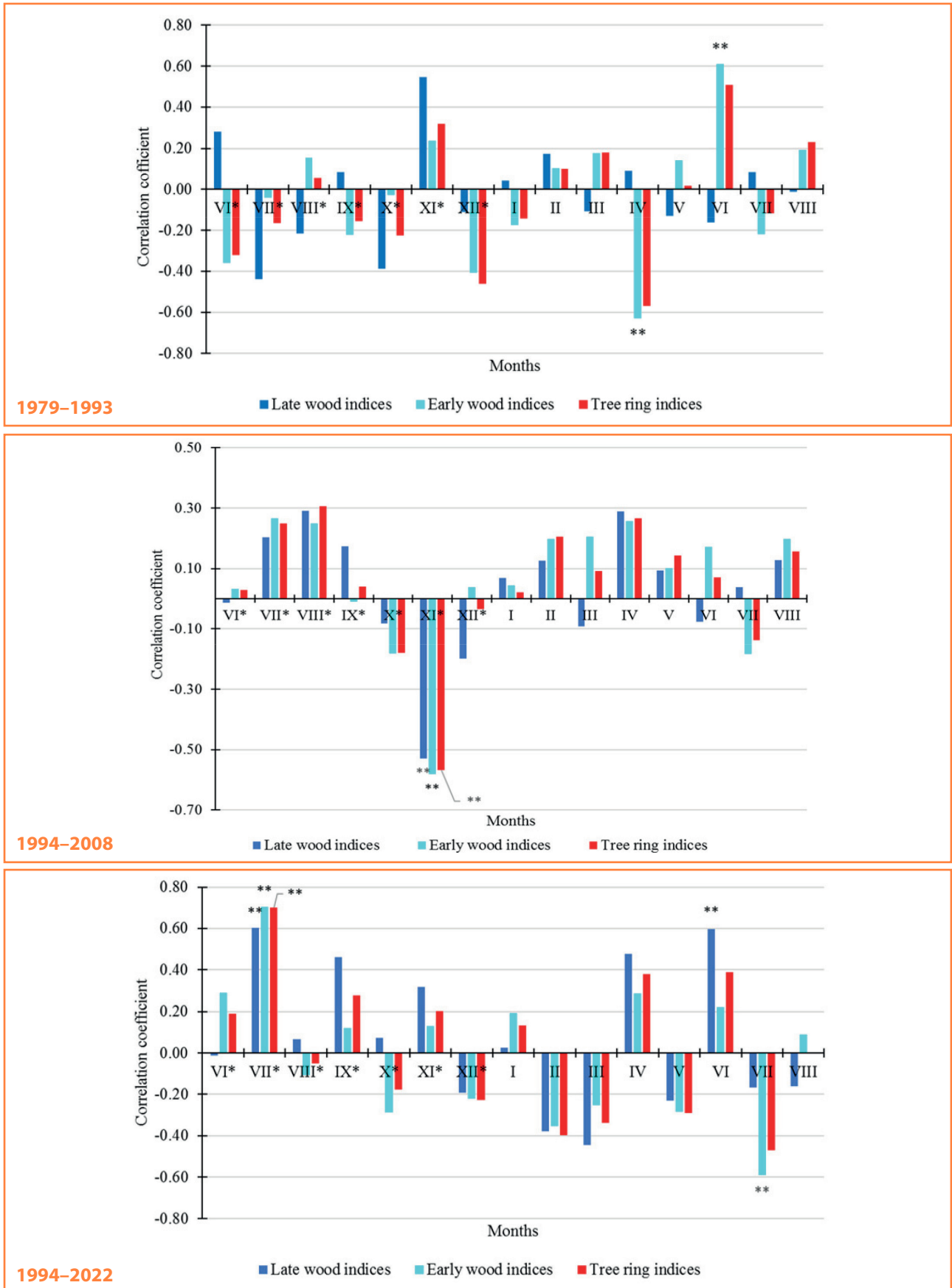
Correlation analysis between indices of different wood species and climatic factors for different periods of the hydrological year showed that early wood was the most sensitive to climate variations, as evidenced by the largest number of significant correlations between index tree-ring chronologies of early wood and climatic factors. For 1979–1993, no significant relationships were found between index tree-ring chronologies of early, late and annual wood and climatic factors; in 1994–2008, an increase in average, maximum and minimum temperatures had a positive effect on tree growth. During the following 2009–2022, the situation changed dramatically: average, maximum temperatures and precipitation during the hydrological year had a negative effect on the formation of early and annual wood layers (Table 1).

The study uses hydrothermal coefficients for dendroclimatic analysis. No significant correlations were found between the radial growth indices of larch and the Selyaninov GTC (formula 5), where Martonne (formulas 1, 2) was not found. Negative significant relationships were established between tree-ring chronologies and hydrothermal indices  $O_1$  (formula 6) and  $O_3$  (formula 7) and SPI (formula 4) in 2009–2022, which indicates an increase in the sensitivity of radial growth of trees in the third period (Table 2).

**Table 1** Correlation coefficients between index tree-ring chronologies and climatic factors

Climate factors	Period (years)		
	1979–1993	1994–2008	2009–2022
<b>Early wood</b>			
Winter temperature T (K)	-0.13	0.53*	-0.46
Winter maximum temperature T (K)	-0.25	0.53*	-0.48
Winter minimum temperature T (K)	-0.10	0.54*	-0.52
Hydrological year temperature T (K)	-0.23	0.33	-0.55*
Hydrological year precipitation (mm)	-0.08	-0.14	-0.54*
<b>Tree ring width</b>			
Winter minimum temperature T (K)	-0.02	0.53*	-0.48
Hydrological year temperature T (K)	-0.13	0.39	-0.56*
Hydrological year maximum temperature T (K)	-0.15	-0.20	-0.54*

\* – correlation level at 0.05, \* significance level



**Figure 4** Correlation analysis between tree-ring chronologies of early, late, and annual wood and temperatures \* – months of the previous year; \*\* – significance at the 0.05 level

**Table 2** Correlation coefficients between radial growth indices and hydrothermal indices

Hydrothermal indices	Period (years)		
	1979–1993	1994–2008	2009–2022
<b>Early wood</b>			
O1	-0.20	0.34	-0.55**
O3	-0.18	0.29	-0.53**
SPI	0,12	0.21	-0.53**
<b>Late wood</b>			
O1	0.22	0.38	-0.47
O3	0.24	0.23	-0.20
SPI	0.09	0.20	-0.44
<b>Tree ring width</b>			
O1	-0.07	0.37	-0.56**
O3	-0.13	0.25	-0.44
SPI	0.12	0.17	-0.53**

\* – correlation level at 0.05 significance level

Studies of European larch trees (*Larix decidua* Mill.) in Poland have shown that the radial growth of trees responds poorly to dry summers and precipitation deficits (Danek & Chuchro, 2019; Szymański et al., 2025). Similar results were also obtained in our studies, as evidenced by a decrease in the radial growth of Japanese larch in 2009–2022 compared to the previous 1979–2008 and the negative impact of the average and maximum temperatures of the hydrological year in this period. Moreover, significant negative correlations between tree-ring chronologies of early and annual wood and hydrothermal coefficients  $O_1$  (formula 6),  $O_3$  (formula 7) and SPI (formula 4) evidence increased sensitivity to climate change.

Studies of the response of radial growth of European Larch (*Larix decidua* Mill.) in the Polish Sudetes to climate change during 1940–2010 recorded an increasing positive relationship of tree-ring growth with May temperatures and precipitation in July of the previous year and a negative relationship with previous August temperatures of the previous year. In the 1980s, there was a rapid change in the level of correlation for the above-mentioned factors. These trends in correlation can be associated with the increasing temperature in recent decades (Danek & Chuchro, 2019). We found a significant positive effect of January temperatures on growth, a negative effect of April precipitation and a positive effect on June precipitation in 1979–1993, a negative effect on precipitation in November of the previous year in 1994–2008 and correlation coefficients between the radial growth of Japanese larch and the positive effect of July precipitation of the previous year, the positive

effect of June precipitation, and the negative effect of July precipitation on radial growth of Japanese larch.

#### 4 Conclusions

This study presented local tree chronologies of early, late, and annual wood of Japanese larch developed in the conditions of the Left Bank forest-steppe, considering three periods: 1979–1993, 1994–2008, and 2009–2022.

The results have shown that in the third period (2009–2022) the sensitivity of radial growth of trees to climate variations increased, as evidenced by an increase in the number of significant correlation coefficients between index tree-ring chronologies and climatic factors (temperatures and precipitation) and hydrothermal coefficients. This indicates a plantation weakening. Early wood was most sensitive to climate variations. The radial growth trend stabilized in 2019–2022. It is necessary to continue dendroclimatic studies of Japanese larch in the Forest-Steppe in order to identify the adaptive capabilities of this species to climate change more accurately.

#### References

- Atramentova, L. O., & Utevska, O. M. (2007). *Statistical methods in biology*. V.N.Karazin KhNU.
- Bitvinskas, T. T. (1974). Dendroclimatic research. *Gidrometeoizdat*.
- Cook, E.R., & Kairiukstis, L.A. (1990). *Methods of Dendrochronology*. Applications in the Environmental Sciences. International Institute for Applied Systems Analysis.

- Danek, M., & Chuchro, M. (2019). Temporal Variations in Tree-Ring Growth Response to Climate of European Larch (*Larix decidua* Mill.): An Example from Sudetes, Poland. *Conference Series: Earth and Environmental Science*, 221. <https://doi.org/10.1088/1755-1315/221/1/012117>
- Debrinyuk, Yu.M., & Belelya, S. O. (2019). Expanded modernization of forest plantations in Ukraine. *Scientific Bulletin of UNFU*, 27(8), 45–51. <https://doi.org/10.15421/40270806>
- Fuchylo, Y. D., Sbytna, M. V., Debryniuk, Y. M., Hayda, Y. I., & Belelia, S. O. (2018). Perspectives of use of larch for creation of forest plantations in the conditions of Ukraine. *Scientific Bulletin of UNFU*, 27(10), 26–32. <https://doi.org/10.15421/40271003>
- Führer, E., Horváth, L., Jagodics, A., Machon, A., & Szabados, I. (2011). Application of a new aridity index in Hungarian forestry practice. *Quarterly Journal of the Hungarian Meteorological Service*, 115 (3), 205–216.
- 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>
- Keyantash, J. (2023, 19 August). *The Climate Data Guide: Standardized Precipitation Index (SPI)*. <https://climatedataguide.ucar.edu/climate-data/standardized-precipitation-index-spi>
- Koval, I., & Maksymenko, N. (2020). The radial increment of European ash (*Larix decidua* L.) under climate change, Ukraine. *Journal of Forest Science*, 66(7), 288–298. <https://doi.org/10.17221/37/2020-JFS>
- Los, S., Grygoryeva, V., Samoday, V., & Neyko, I. (2018). Complex assessment of larch species and hybrids perspectives for the Forest-Steppe of Ukraine conditions. *Proceedings of the Forestry Academy of Sciences of Ukraine*, (16), 62–69. <https://doi.org/https://doi.org/10.15421/411807>
- Meshkova, V., Pyvovar, T., & Tovstukha, O. (2019). Health condition parameters for deciduous trees in the forest stands of Trostyanetske Forest Enterprise. *Proceedings of the Forestry Academy of sciences of Ukraine*, 18, 129–137. <https://doi.org/https://doi.org/10.15421/411913>
- Milentijević, N., Dragojlović, J., Ristić, D., Cimbajević, M., Demirović, D., & Valjarević, A. (2018). The assessment of aridity in Leskovac Basin, Serbia (1981–2010). *Journal of the Geographical Institute "Jovan Cvijić"*, 68 (2), 249–264. <https://doi.org/10.2298/IJGI1802249M>
- Ostapenko, B. F., & Sytnik I. Y. (2011). *Parks of V. V. Dokuchaev Kharkiv National Agrarian University*. Kharkiv National Agrarian University.
- Shvidenko, A., Buksha, I., Krakovska, S., & Lakyda, P. (2017). Vulnerability of Ukrainian Forests to Climate Change. *Sustainability*, 9(7), 1152. <https://doi.org/10.3390/su9071152>
- Szymański, N., Wilczyński, S., Kowalczyk, J., & Wojciech Kowalkowski. (2025). The tree-ring width and interval trend values as indicators of sensitivity to temperature and precipitation in different provenances of European larch. *Scientific Reports*, 15, 1656. <https://www.nature.com/articles/s41598-025-85652-5>

