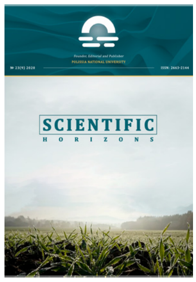
SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua

Scientific Horizons, 25(10), 17-30



UDC 630*4:574.3

DOI: 10.48077/scihor.25(10).2022.17-30

Early and Late Wood of Scots Pine under Conditions of Varying Degrees of Lighting

Olena Andreieva[1*], Iryna Koval[2], Vitaly Smolin[3]

[1]Polissia National University
10008, 7 Staryi Blvd., Zhytomyr, Ukraine

[2]Ukrainian Research Institute of Forestry and Forest Melioration named after G. M. Vysotsky
61024, Pushkinska Str., 86, Kharkiv, Ukraine

[3]National University of Life and Environmental Sciences of Ukraine
03041, Heneral Rodimtsev, 19, Kyiv, Ukraine

Article's History:
Received: 10/03/2022
Revised: 11/15/2022
Accepted: 12/07/2022

Suggested Citation:
Andreieva, O., Koval, I., & Smolin, V. (2022). Early and late wood of scots pine under conditions of varying degrees of lightingt. *Scientific Horizons*, 25(10), 17-30.

Abstract. The condition of pine stands in Polissia is deteriorating due to an increase in the number of outbreaks of sharp-dentated bark beetle (*Ips acuminatus*) against the background of climate change, therefore, the relevance of this problem is beyond doubt. The purpose of the study is to identify the features of the dynamics of late and early Scots pine wood (*Pinus Sylvestris* L.) in areas with varying degrees of illumination after continuous cutting in the foci of the sharp-dentated bark beetle (*Ips acuminatus*) in Polissia. Standard dendrochronological, dendroclimatic, and statistical methods are used. It is established that after continuous logging in 2013 in the adjacent areas, on the one hand, there was an increase in the radial growth of pine trees, because the nutrition areas increased and the lighting conditions of trees improved, and on the other hand, trees growing next to the logging area are weakened and have fragile cores, which indicates a loss of wood quality. After cutting, during 2014-2020, the average values of late pine trees of illuminated time trial areas compared to the corresponding values in the control were 43-45%. For early wood, these values ranged from 38-42%. The growth change indices showed, that after the 2013 logging, violations occurred for trees in illuminated temporary trial areas as opposed to the control. The most sensitive to climatic factors were tree-ring chronologies of late wood in the most illuminated trial area. An increase in the sensitivity of the radial growth of pine trees was found depending on the increase in the degree of illumination. The weakening of plantings in the most illuminated area is indicated by the fact that the greatest number of significant relationships between growth and climate were found for the tree-ring chronology of early and late wood, while there was no critical decrease in trends in late and early wood layers. The findings can be used for planning forest management activities

Keywords: *Pinus sylvestris* L., *Ips acuminatus*, tree-ring chronologies of early and late wood, continuous logging, indices of growth changes, climatic factors

Copyright © The Author(s). This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/)

*Corresponding author

INTRODUCTION

Scots pine (*Pinus sylvestri*s L.) responds to an increase in temperature by reducing the functions of the hydraulic system, mainly the protection system. V.L. Meshkova proved that warming is a favourable condition for bark beetles, that is, the growing seasons lengthen, the growth and development rates of larvae accelerate, the reproductive potential and the success of overwintering increase. Consequently, the pest population is growing and the pressure on weakened trees is increasing. Pests can adapt to new conditions, create new populations, quickly settle and cause huge damage, which leads to the deterioration of forests and their drying up. Extreme climatic conditions have been gaining momentum since the 1880s and are considered a long-term factor increasing the mortality of Scots pine trees (*Pinus sylvestris* L.). Weather monitoring over the past 120 years shows that in Europe, air temperatures are rising at a rate of 0.18°C per decade. Bark beetles and their increasing outbreaks accelerate and enhance the impact of forest ecosystems' sensitivity to climate fluctuations (Meshkova, 2021).

C.F. Aoki and colleagues from the USA also found that in recent years, high temperatures that coincided with periods of drought have led to an increase in the number of outbreaks of sharp-dentated bark beetles (*Ips acuminatus*). Sharp-dentated bark beetle is one of the most dangerous pests of pine stands, which among wetland coniferous, wetland mixed pine-oak, upland (dry) coniferous, and upland mixed pine-oak plantations with a high percentage of pine were more likely to be infested than mixed pine-deciduous plantations (Aoki *et al*., 2018).

Scots pine is one of the main forest-forming tree species in Ukraine, which occupies 33% of the entire wooded area. Studies by V.L. Meshkova and O.I. Borysenko revealed that the predominant development of Scots pine dying in Polissia is associated with a large proportion of same-age pure pine stands, untimely thinning and relatively slow drying of felling residues, in which the bark beetle has time to complete its development. An algorithm for predicting the spread of bark beetle foci has been developed. This helps to improve the accuracy of the forecast, evaluate the survey area and pest control measures (Meshkova & Borysenko, 2018). O.Yu. Andreieva and A.F. Goychuk also emphasises that only timely removal of colonised trees can slow down the decline of pine forests (Andreieva & Goychuk, 2018; Andreieva & Goychuk, 2020).

Mortality of pine trees, which can be attributed to *I. acuminatus*, is widespread in the surveyed area of southern Finland, which was proved by J. Siitonen. The researcher found that in the dead-standing trees, the passages *I. acuminatus* are located at the top of the trunks, usually at a height of more than 5 metres, and binoculars are needed to identify passages from the ground. This means that the passages on dead trees will go unnoticed. On the other hand, *I. acuminatus* also breeds in fallen pines and logging remains with thin bark (Siitonen, 2014). However, information on the impact of cambioxylophagous pests on the condition of Scots pine in Europe is still insufficient (Frelich *et. al.,* 2021).

Dendrochronological methods are widely used in modern research on the dynamics of forest ecosystems, the response of plantings to climate change, and the assessment of plant damage and productivity (Huang *et al*., 2021; Soulé *et al*., 2021; Sun *et al*., 2021). Radial tree growth is a bioindicator that can be used to determine the level of forest damage, the response of trees to climate stress factors (Koval, 2020; Kipfmueller *et al*., 2022), increased lighting, etc. (Altman, 2020; Carter *et al*., 2021; Kraj *et al*., 2022).

An increase in the radial growth of trees after a disturbance is often referred to as a release, because after it, subdominant trees are released from the suppression of dominant trees (Altman, 2020; Carter *et al*., 2021; Venegas-González *et al*., 2022). The forest's response to disturbance depends on the magnitude, severity, and type of disturbance, which alter the succession trajectory and productivity of affected forests with significant implications for their future diversity and structure. This is partly conditioned by reduced underground competition for nutrients and aboveground competition for light (Kern *et al*., 2017; Danneyrolles *et al*., 2019; Altman, 2020), residual tree species that are not hosts benefit from such disturbances (Bretfeld *et al*., 2015). Previous studies have shown that in forests in the western United States, outbreaks of bark beetles that infect conifers have led to the rapid release of aspen (*Populus tremuloides Michx*.). However, the effect of the level of natural disturbances on such bursts of radial increment remains largely unknown. By counting dated bursts from numerous series of tree rings, it is possible to reconstruct the history of tent disturbance in a given forest area (Radaković & Stajić, 2021).

Intense, widespread disturbances responsible for at least strengthening the overall trend of climate change can affect the sensitivity of trees to climate factors (Frelich *et al*., 2021). K. Izworska *et al.* found that changes in the condition of trees after, for example, a windfall, when the stand is thinned, may be associated with a lack of water in an open stand in the summer, which was confirmed by a correlation analysis that showed an increase in the dependence of the radial growth of European larch (*Larix decidua* Mill.) in the summer from precipitation in the Slovak Tatras. The growth response of surviving larch trees after a windfall in plantings that are illuminated after this phenomenon can be compared to a similar response associated with a shift towards a lower altitude in the mountains or with a shift towards a more continental climate, where high summer temperatures and water scarcity are factors limiting tree growth (Izworska *et al*., 2022).

Due to the fact that the radial growth of trees is a complex indicator that reflects the state of trees in forest ecosystems, it makes sense to use dendrochronological methods in the study of plantings under the influence of changes in the natural environment due to continuous logging in the cells of the sharp-dentated bark beetle.

The purpose of the study consists in identifying the dynamics of late and early Scots pine wood (*Pinus Sylvestris* L.) after continuous sanitary logging in the foci of the sharp-dentated bark beetle (*Ips acuminatus*) in Polissia, in areas with different degrees of illumination.

MATERIALS AND METHODS

In pure same-age pine (compartment 22, department 25 of SE "Korostyshivske Forestry" Zhytomyr Regional Forestry and Hunting Range Administration) in wet subor conditions, three temporary trial areas (TTA) were established – on the south-eastern (most illuminated), north-western (least illuminated) sides of the area of continuous logging in 2013 in the focus of the sharp-dentated bark beetle and in the forest (control). The studied pure middle-aged pine stands grow in genetic reserves. The climate of the region under study is moderately continental. The average annual air temperature is 9.1°C. In January, this figure reaches -3.2°C, and in July – 20.5°C. 662.6 mm of precipitation falls per year, and 358 mm during the growing season (April-September). The analysis of cores (20 from each TTA) selected in 2020 was carried out using standard dendochronological and statistical methods (Cook & Kairiukstis, 1990).

To take samples of wood cores, a Swedish-made age drill (Haglof) was used to take cores with a diameter of 5 mm at a height of 1.3 m from the ground perpendicular to the longitudinal axis of the tree. The cores were placed in paper containers in which they were transported, dried, and stored. The next step was the laboratory investigation of the samples. The surface of the cores was carefully cleaned with a blade. To increase the contrast when measuring layers of late, early and summer wood, the surface of the cores was moistened with water, or chalk was rubbed into the sample. Layers of late and early wood were measured using the Henson digital instrument with an accuracy of 0.01 mm (Bitvinskas, 1974; Fritts, 1976; Cook & Kairiukstis, 1990).

Based on the measurement data, radial increment graphs are constructed for each tree, which are used for cross-dating (Holmes, 1983). The result of cross-dating is the establishment of a calendar date for each layer of wood, when performing cross-dating, extreme growth values (extremely narrow or wide layers of summer wood) were used, including rings that have a pathological structure (frost-resistant, light false rings, etc.), which are usually used to determine the correctness of dating. Segments of cores with low correlation values and cores that were not subject to dating were excluded from the sample. Methods of comparative and intra-row analysis are used to investigate general trends in changes in the radial growth of trees over time, identify growth extremes and relationships of radial growth indices with meteorological conditions.

20 samples of wood cores were taken by Presler drill from the tree trunk at a height of 1.3 m from each TTA. The values of late and early wood layers were measured with a HENSON digital instrument with an accuracy of 0.01 mm. Cross-dating was performed to determine the date of formation for each layer of wood. The concept of reference years is used to study the extreme values of radial growth, when the value of the annual ring of the current year is less or greater than the corresponding value of the previous year by 25% and 75% of trees in the sample have the same trend. A comparative analysis was performed between the chronology of pine trees in the illuminated areas and the corresponding values in the control. Tree-ring chronologies are calculated by three-year smoothing. Correlation analysis was applied to identify the relationship between radial tree growth and climate factors.

For dendroclimatic analysis, data from the Zhytomyr weather station was used (geographical coordinates: latitude: 50°15'53" N, longitude: 28°40'36" E, the height above sea level is 228 m). The influence of monthly precipitation amounts and average monthly temperatures on the radial growth of trees from June of the previous year to August of the year of study is analysed, and the relationship between the radial growth of pine trees and the hydrothermal indices according to Selyaninov, which reflects the conditions of the growing season; De Martonne, which contains information on the hydrothermal conditions of the current year and O_3 according to T.T. Bitvinskas, which reflects the hydrothermal conditions of the three previous and current years (Bitvinskas, 1974).

To identify violations in plantings under the influence of stress factors, growth change indices were calculated (*GCt*) for the year of damage (*t*), which are universal for all types of species and growing conditions (Cook *et al.*, 1990).

$$GGt = \frac{Agr2 - Agr1}{Agr1 * 100} \tag{1}$$

where $Agr1$ – average annual growth for the period n 1 before the year characterised by stress factors (t); $Agr2$ – average annual growth for the period n 2 after the action of the stress factor.

It is considered that changes in growth occurred when the index GGT exceeded the threshold of 25%. A significant violation in the planting occurs when GGT≥75%, average between 50 and 75%, and insignificant between 25 and 50%. Growth change indices are universal for all types of species and growing conditions. Using a window of reasonable length, this method filters out the response to short-term changes in temperature and precipitation. In practice, the percentage increase in growth is calculated for all possible pairs of consecutive pre- and post-windows of different values. Correlation analysis was used to establish the relationship between late and early wood on the one hand and climatic factors on the other.

RESULTS AND DISCUSSION

Late wood. It was found that the cores selected from Scots pine from the forest side are of higher quality, in contrast to the cores that are selected on the less illuminated northwest side of the logging area and the more illuminated southeast side of the logging area and which are extremely fragile. The widest layers of late wood were observed in trees on the most illuminated side, and a "release" growth was observed on the less illuminated part of the logging area, and the narrowest layers of late wood were characteristic of trees in the control area. Comparison of the size of layers of late Scots pine wood for two periods – 2006-2012 and 2014-2020. In areas with less illumination, layers of late pine wood increased by 22% in the second period (2014-2020) compared to the first period (2006-2012). At the same time, at the more illuminated TTA, this excess was 13%. For trees from the control TTA, the opposite process occurred – the values of late wood layers decreased by 24%. After 2019, the trend of late Pine layers began to decrease in illuminated areas, but this decline was not critical (Fig. 1, Table 1).

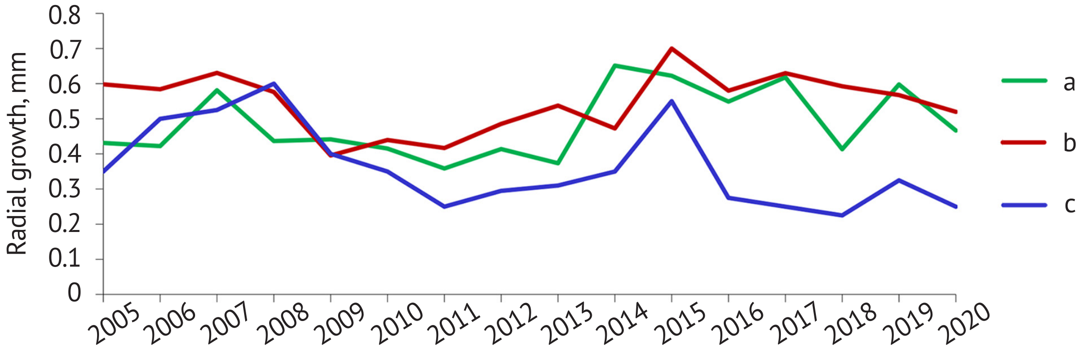


***Figure 1**. Dynamics of layers of late Scots pine wood at the TTAs with different lighting levels near the logging area of 2013*

***Note:** a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side; c – forest side*

***Source:** compiled by the authors*

***Table 1**. Comparison of late Scots pine wood values at the TTA with different lighting levels for 2006-2012 and 2014-2020*

Area of sampling	Statistical factors	2006-2012	2014-2020	Reliability of the difference between the average values of radial growth for 2006-2012 and 2014-2020	
				t_{fact}	t_{theor}
a	A_{avg}/m	0.44 ± 0.03	0.56 ± 0.03	$2.86_{0.05}$	1.76
	σ	0.07	0.09		
	$σ^2$	0.005	0.008		
b	A_{avg}/m	0.50 ± 0.04	0.58 ± 0.03	$1.70_{0.05}$	1.76
	σ	0.09	0.07		
	$σ^2$	0.009	0.005		
c	A_{avg}/m	0.42 ± 0.05	0.32 ± 0.04	$1.54_{0.05}$	1.76
	σ	0.129	0.112		
	$σ^2$	0.002	0.001		

***Note:** a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side of the logging area; c – forest side; A_{avg} – average value of the annual wood layer; m – error of the average annual wood layer; σ – standard square deviation; $σ^2$ – variance*

***Source:** calculated by the authors*

The excess of the average values of late wood layers for trees with less illuminated and more illuminated TTAs is comparable to the corresponding values in the control for the post-felling period (2014-2020 PP.) was 43 % and 45 %. This excess was significant: for less illuminated and more illuminated TTAs compared to the corresponding values for the control area for 2014-2020 (t_{fact}=4.49 and, respectively, t_{fact}=4.79005, t_{theor}=1.76. That is t_{fact}> t_{theor} indicates a rejection of the zero hypothesis that there is no difference between the samples (Gorkavy, 2019).

Early wood. The average values of early wood layers for the periods before continuous cutting in 2013 (2006-2012) and after it (2014-2020) are compared. It was found that in the second period, the excess of the values of early wood layers for trees with TTA on the less illuminated side compared to the first period was 20%, while for trees with more illuminated TTA, the corresponding value was 9%. The growth of early wood, on the contrary, decreased slightly (by 3%) for trees growing in the control area. After 2019, the radial growth of pine trees in illuminated areas began to decrease sharply, in contrast to the control (Fig. 2).

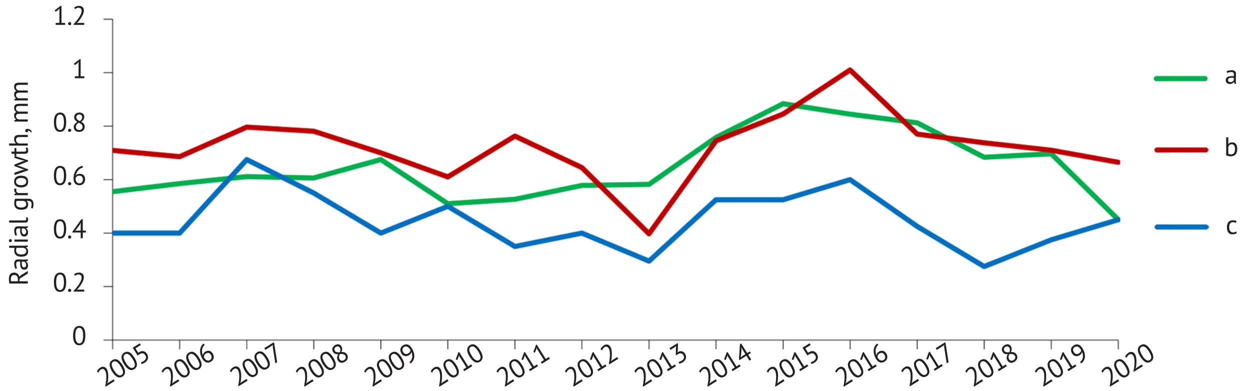


Figure 2. *. Dynamics of layers of early Scots pine wood at the TTA with different lighting levels near the logging area of 2013*
Note: *a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side; c – forest side*
Source: *compiled by the authors*

When comparing the average values of early wood layers for the two periods 2006-2012 and 2014-2020, a significant difference was found only for trees growing in less illuminated TTA compared to trees growing in other areas. The average values of early wood layers on the side of a less illuminated TTA exceed the corresponding values at the control by 38%, and at the TTA with more lighting – by 42% (Table 2).

Table 2. *Statistical characteristics of layers of early Scots pine wood near the logging area of 2013*

Area of sampling	Statistical factors	2006-2012	2014-2020	Reliability of the difference between the average values of radial growth for 2006-2012 and 2014-2020	
				t_{fact}	t_{theor}
a	A_{avg}/m	0.58 ± 0.02	0.73 ± 0.05	$2.53_{0.05}$	1.76
	σ	0.056	0.14		
	σ^2	0.003	0.02		
b	A_{avg}/m	0.71 ± 0.03	0.78 ± 0.04	$1.41_{0.05}$	1.76
	σ	0.071	0.114		
	σ^2	0.005	0.013		
c	A_{avg}/m	0.473 ± 0.04	0.453 ± 0.04	$0.23_{0.05}$	1.76
	σ	0.114	0.108		
	σ^2	0.013	0.011		

Note: *a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side of the logging area; c – forest side;* A_{avg} *– average value of the annual wood layer; m – error of the average annual wood layer;* σ *– standard square deviation;* σ^2 *– variance*
Source: *calculated by the authors*

The average values of layers of early wood of trees with TTAs with different degrees of illumination and trees from the forest side for 2014-2020 are compared. A significant difference was found between the average values of early wood layer values for trees with less illuminated TTA and the corresponding values for trees with control TTA (t_{fact}4.08>t_{theor}1.76 at the significance level of 0.05).

Growth change indices (*GCt*) for the year of damage (*t*), which express the degree of disturbance of plantings, calculated for TTAs with different lighting levels for 2013, during which continuous logging took place, is the year of the stress factor's action. The growth change indices are calculated with a 3-year window for 2010-2012 and 2014-2016. It was found that after logging in 2013, violations occurred at all at the TTAs for late wood, as opposed to early wood, where no changes occurred at the control, which indicates a greater sensitivity of late wood to changes in environmental conditions (Table 3).

***Table 3**. Statistical characteristics of layers of early Scots pine wood near the logging area of 2013*

Area of sampling	A_{avg}, mm/*m*		GC_t, %	Degree of violation
		Late wood		
a	0.40 ± 0.019	0.61 ± 0.03	53	Average violation
b	0.447 ± 0.020	0.584 ± 0.065	31	Minor violation
c	0.354 ± 0.006	0.455 ± 0.064	29	Minor violation
		Early wood		
a	0.538 ± 0.020	0.866 ± 0.077	61	Average violation
b	0.672 ± 0.046	0.866 ± 0.077	29	Minor violation
c	0.377 ± 0.024	0.463 ± 0.049	23	No changes occurred

Note: *a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side of the logging area; c – side of the forest; GCt – index of changes in growth after a violation of the stand due to continuous logging in 2013.; A_{avg} – average value of the annual wood layer; m – error of the average annual wood layer*
Source: *calculated by the authors*

Percentage of late wood. The proportion of late wood is calculated for trees with different degrees of illumination. In 2013, in the year of logging at the most illuminated TTA, the share of late wood was 57.5%, at the less illuminated TTA – 39.1%, and at the control – 40%. That is, the proportion of late wood was highest in the most illuminated TTA, which may indicate a deterioration in the condition of the plantings. Later, during 2014-2020, the share of late wood in the most illuminated TTA ranged from 36.5-45.0%, in the less illuminated TTA – 37.7-50.9%, and in the control TTA – 31.4-51.2%. That is, thinning during this period did not significantly affect the percentage of late wood (Fig. 3).

***Figure 3**. The share of late Scots pine wood near the logging area of 2013*
Note: *a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side; c – forest side*
Source: *compiled by the authors*

Influence of late and early wood climate on TTA with different lighting levels. A significant positive effect of March temperatures on late pine wood in a less illuminated TTA was found. At the same time, the temperatures of the growing season and autumn months of the previous year negatively affected the formation of layers of late wood. It was found that at the most illuminated TTA, the dependence of late wood on temperatures increased, as evidenced by the largest number of significant correlations between temperatures and late wood indices compared to other TTA. Significant positive correlations were found between late wood indices and winter and hydrological year temperatures. On less illuminated TTA, the positive effect of temperatures on late wood during the growing season and winter increased. For the control TTA, a significant positive effect of temperatures on late wood was found in November of the previous year and a negative effect of temperatures during August. Overall, the most negative effect of temperatures on late wood during the growing season was observed for trees with the control TTA. For trees for the most illuminated TTA, on the contrary, this effect was positive, while trees of the less illuminated TTA occupied an intermediate position (Fig. 4).

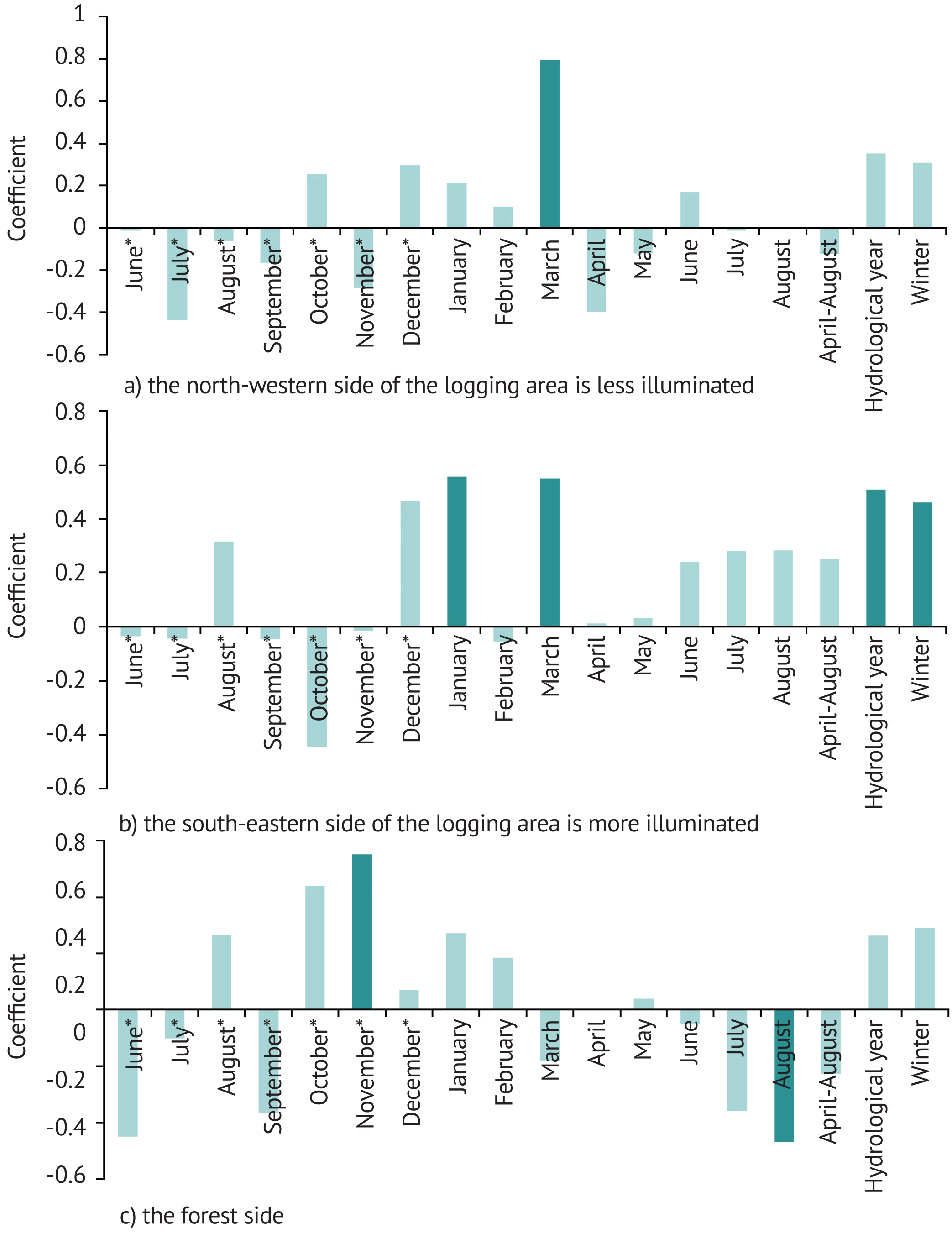


***Figure 4**. Correlation coefficients between the indices of late Scots pine wood in areas with different lighting levels due to continuous logging in 2013 and the temperature of the Zhytomyr weather station for 2006-2019*

***Note:** * – months of the previous year, dark green column –significant correlation coefficient at the level of 0.01 significance*

***Source:** compiled by the authors*

The relationship between late wood and precipitation indices is analysed. For a less illuminated TTA, a positive effect of precipitation in June of the previous year and the current June on late wood was found. For a more illuminated TTA, a negative effect of precipitation from the previous September on the values of late wood layers was found. At the same time, for the control TTA, precipitation in August of the previous year and the growing season had a positive effect on the formation of late wood layers. Precipitation in June-August of the previous year mainly had a positive impact on the formation of late wood layers. The exception was the less illuminated TTA, which showed a significant effect of precipitation on late wood only for June of the previous year. From September 2019 to April 2020, a negative effect of precipitation on growth was found for all plots, while during the growing season, the strongest positive effect of precipitation was found for the control. Winter precipitation negatively affected radial growth at all TTAs. Precipitation in July and August is the main factor controlling the formation of late wood layers. For the control TTA, a significant effect of August precipitation on the formation of late wood layers was found (Fig. 5).

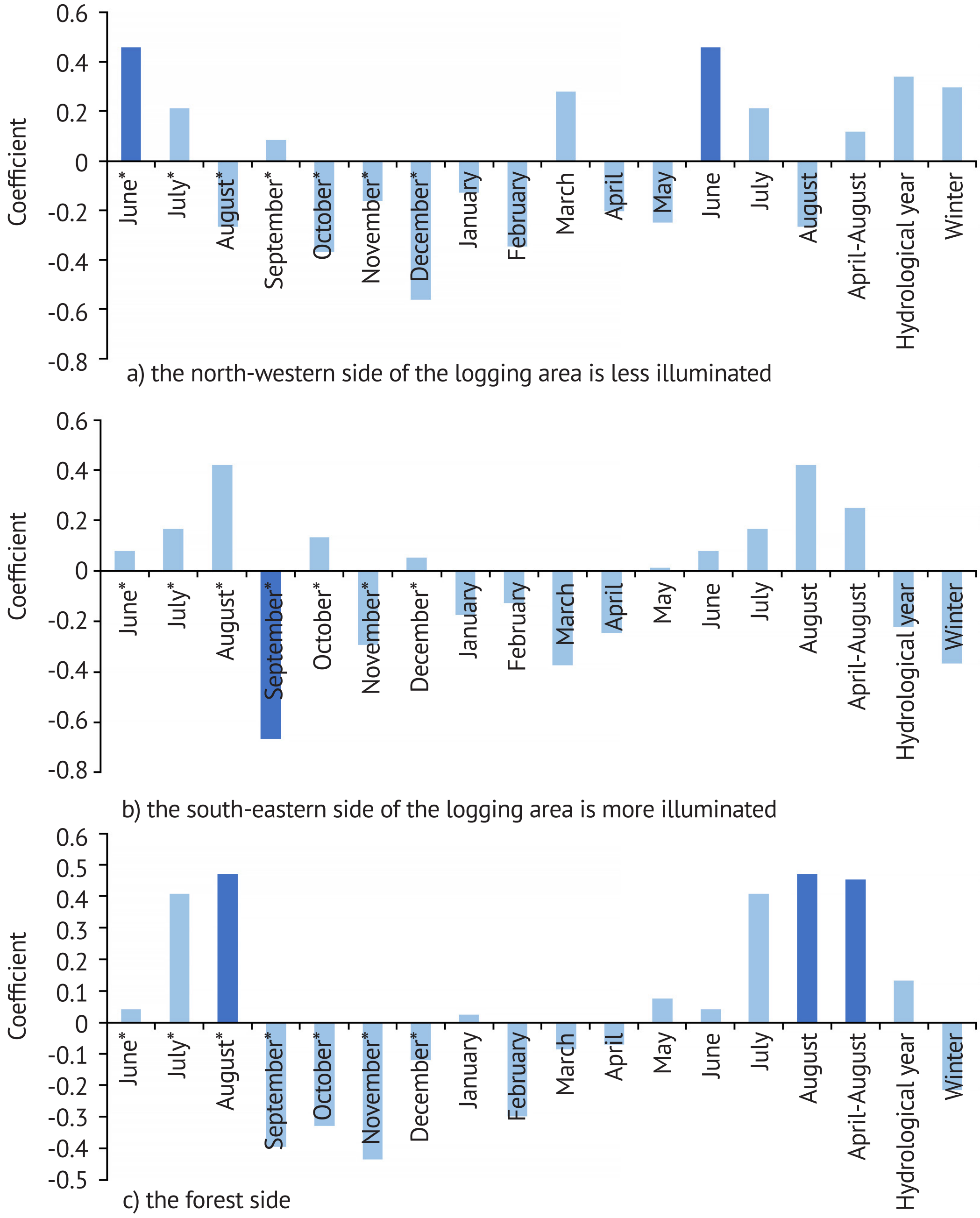


***Figure 5**. Correlation coefficients between the indices of late Scots pine wood in areas with different lighting levels due to continuous logging in 2013 and the temperature of the Zhytomyr weather station for 2006-2019*

***Note:** * – months of the previous year, dark green column –significant correlation coefficient at the level of 0.01 significance*

***Source:** compiled by the authors*

Consequently, it was found that on more illuminated TTA, late wood was more sensitive to temperature, while the tree-ring chronologies of late wood at the control TTA were more sensitive to precipitation.

A correlation analysis was performed between *early wood indexes* and temperatures. A positive effect of December temperatures of the previous year was found for two TTAs – more illuminated and the control. A significant positive effect of March temperatures on the formation of early wood layers was found for all areas with different illumination levels. July temperatures of the current year had a positive effect on the formation of early Scots pine wood at the control. Significant correlations between early wood indices and average hydrological year temperatures were found for a more illuminated area and control. From May to August, there was a positive effect of temperatures on early wood at the control, while in illuminated areas this effect was mainly negative (Fig. 6).

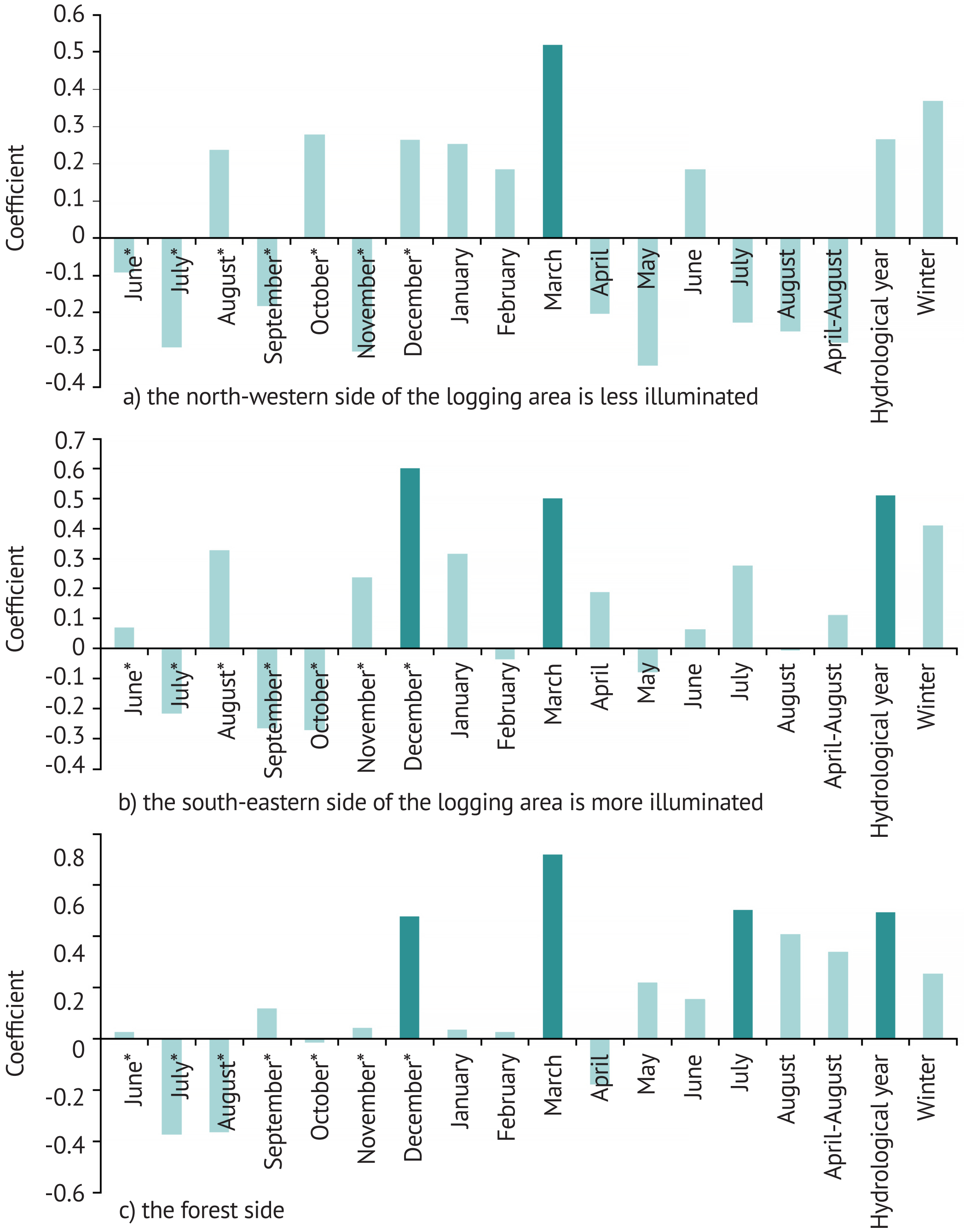


***Figure 6**. Correlation coefficients between the indices of early Scots pine wood in areas with different lighting levels due to continuous logging in 2013 and the temperatures of the Zhytomyr weather station for 2006-2019*
***Note:** * – months of the previous year, dark green column –significant correlation coefficient at the level of 0.01*
***Source:** compiled by the authors*

Correlations between early timber indices and precipitation over different periods were calculated. Significant negative correlations were found between early timber indices and October and December precipitation of the previous year for illuminated TTA and the control. Overall, precipitation from the previous year had a positive effect on early wood at the control, while in illuminated areas this effect decreased. In the control from August of the previous year to May of the current year (with the exception of March), the control showed a negative effect of precipitation on early wood (Fig. 7).

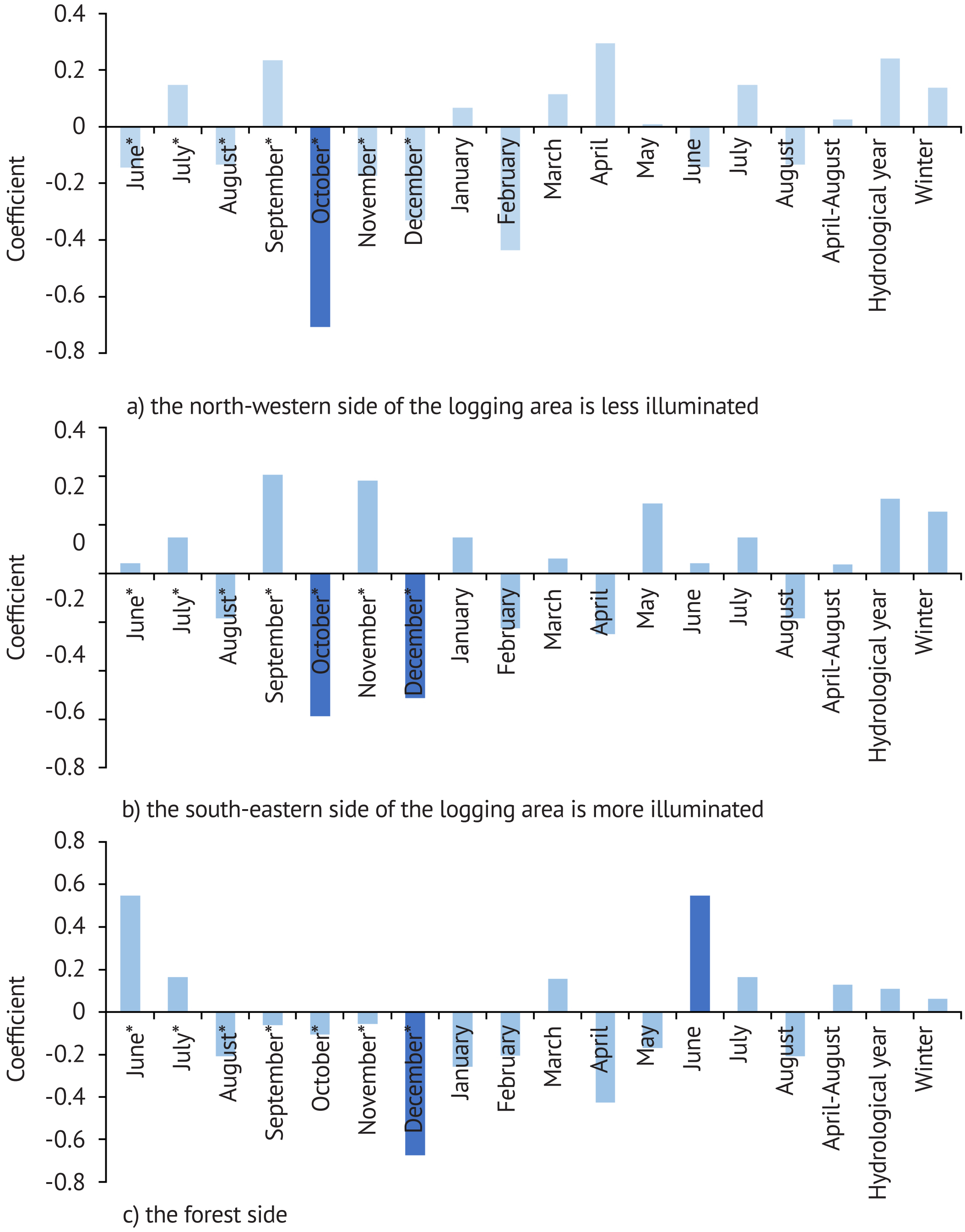


Figure 7*. Correlation coefficients between the indices of early Scots pine wood in areas with different lighting levels due to continuous logging in 2013 and precipitation of the Zhytomyr weather station for 2006-2019*
Note: ** – months of the previous year, dark blue column – significant correlation coefficient at the level of 0.01 significance*
Source: *compiled by the authors*

The relationship between hydrothermal coefficients and late and early wood indices was studied. Significant mean negative relationships were found between early wood for illuminated TTA on the one hand and hydrothermal index, De Martonne, and O_3 indices – on the other side (Table 4).

Table 4. Correlation coefficients between tree-ring chronologies of Scots pine growing in conditions with different lighting levels and hydrothermal coefficients

Hydrothermal coefficients			
Hydrothermal humidification coefficient according to G.T. Selyaninov (hydrothermal index)			
Types of wood	a	b	c
Late wood	-0.15	-0.02	-0.16
Early wood	-0.37	-29.86	-0.28
De Martonne			
Late wood	-0.19	0.17	-0.18
Early wood	-29.86	-29.86	-0.09
O_3			
Late wood	0.19	-0.02	-0.02
Early wood	-0.04	0.11	0.29

Note: ** – significance at the level of 0.05; a – less illuminated north-western side of the logging area; b – more illuminated south-eastern side of the logging area ; c – forest side*
Source: *calculated by the authors*

The study found that early wood was most sensitive to climate changes in illuminated areas, as evidenced by the highest correlation between early wood and the de Martonne aridity coefficient. This coefficient has been preferred in climate research by Spanish scientists because it can better distinguish between different climatic conditions (Moral *et al.*, 2016).

Studies of radial growth of European larch (*Larix decidua*) in a centuries-old group of trees in the Slovak High Tatras, it was found that after the catastrophic storm of 2004, a surge in radial tree growth, which was calculated from the growth change index, occurred within 4.6 years (Izworska *et al.*, 2022). In study study, in a same-age pine stand that is most illuminated, the radial growth of pine occurred faster, that is, the next year after continuous logging.

10-year-old loblolly pine plantation *Pinustaeda* L.) in southeastern Oklahoma (USA) was thinned out. The percentage of late wood, the date of transition from early wood to late, growth and climate variables were measured within two years after logging, which did not significantly affect the percentage of late wood in the annual ring (Cregg, 1988). In this study, the change in the light regime also did not significantly affect the percentage of late wood, that is, its density after continuous logging in 2013 in a pine plantation during 2014-2020.

Studies of the reaction of early and late oak wood (*Quercus petraea* (Matt.) Liebl.) on climate factors in northeastern Serbia, late wood was found to be more sensitive to climate changes than early wood. Late wood showed a positive response to precipitation during the summer months (June and July) of the current growing season. At the same time, the size of early wood layers did not show a direct dependence on climatic factors. It was found that temperature does not significantly affect oak growth. Precipitation during the summer months was a crucial climatic factor that led to years with exceptionally wide or narrow layers of late wood (Radaković & Stajić, 2021). The influence of climatic factors on the growth of black pine, which grows at low altitudes in western France, was estimated by comparing the indices of early and late wood with monthly data on temperature and precipitation for the period of 1922-1991. Late wood formation was found to be more sensitive to climate than early wood formation. It was found that the summer drought was the main factor limiting the growth of trees. The extreme reduction in growth has particularly highlighted the impact of low precipitation (Lebourgeois, 2000). In the control, a higher dependence of late wood layers was found on precipitation (positive effect for the previous August and April-August), and for early wood – on temperature (positive effect of temperatures in the previous August, March, July, and hydrological year on early wood). After continuous logging in 2013, the dependence of late wood on temperatures increased at the most illuminated TTA.

Winter photosynthesis and an advance in the time of restoration of cambial activity were possible reasons for the positive correlation of winter temperature with early wood. The cool and humid spring also contributed to growth, as it affected the water balance of trees at the beginning of the growing season (Lebourgeois, 2000). The temperature of February is the main climatic factor associated with the radial growth of Scots pine in Latvia (Elferts, 2007). This study also revealed a positive effect of March and winter temperatures on the formation of early and late pine wood.

Studies of the radial growth of Scots pine in Mongolia and China have shown that the growth of natural forests was closely related to the climatic factors of the previous year, while the growth of plantation stands was associated with the climatic factors of the growing season of the current year (Sun *et al.*, 2021). The study by French researchers has established that seedlings of black Pine (*Pinus nigra* ssp. *laricio* VW. Corsicana) had metabolic disorders due to carbon starvation conditioned by droughts (Guehl *et al.*, 1993). This study revealed the influence of climatic factors both in the previous year and in the current year on the formation of layers of early and late pine wood, despite the fact that the studied pine trees are crops. Thus, the most sensitive wood to the hydrological conditions of the growing season and the hydrological year was early wood in the most illuminated area, which is located closest to the logging area. Hydrological conditions negatively affected the formation of early and late wood for the TTA, where the most weakened trees grow, as evidenced by the negative correlation coefficients between the chronologies of early and late wood with the Selyaninov hydrothermal index and the de Martonne index.

Studies of European larch after the windbreak have shown that the main change after the catastrophic phenomenon is associated with a lack of water in an open tent in the summer. This is supported by significant positive correlations between growth and July precipitation. The growth response of larch trees that survived the windfall can be compared to a similar response associated with a shift towards a lower altitude in the mountains or with a shift towards a more continental climate, where high temperatures in mid-summer and water scarcity are factors limiting growth (Izworska *et al.*, 2022). Similar results were obtained in this study. In illuminated areas, the dependence of the increase on temperatures increases, especially for late wood. In these illuminated areas, the negative impact of precipitation in the autumn months of the previous year on early and late wood is also increasing. During these months, the soil moisture reserve is formed for the next year.

CONCLUSIONS

On the borders with the area of the continuous sanitary logging of 2013, the cores of Scots pine selected in 2020 turned out to be extremely fragile, in contrast to the cores selected in the forest. After continuous logging in 2013, a surge in radial growth was observed in 2014 and lasted until 2017, after which it sharply decreased in contrast to the control. For trees in illuminated temporary trial areas, compared with the corresponding values, the control showed an excess of the values of late wood layers by 43-45%, and early – by 38-42% due to an increase in feeding areas and improved lighting conditions. The growth change indices showed, that after the 2013 logging, violations occurred for trees in illuminated temporary trial areas as opposed to the control.

Dendroclimatic analysis revealed an increase in the sensitivity of early and late wood, depending on the increase in the degree of illumination. The weakening of plantings in the most illuminated area is indicated by the fact that for the chronologies of early and late wood, the greatest number of significant relationships between growth and climate were found, while there was no critical decrease in the trends of late and early wood layers. It was found that in more illuminated temporary trial areas, late wood is more sensitive to winter and early spring temperatures, and a positive effect of temperatures during the hydrological year on growth was also found. At the same time, the tree-ring chronologies of late wood on the control are more sensitive to precipitation, and early – to temperatures.

REFERENCES

[1] Altman, J. (2020). Tree-ring-based disturbance reconstruction in interdisciplinary research: Current state and future directions. *Dendrochronologia*, 62, article number 125733. doi: 10.1016/j.dendro.2020. 125733.
[2] Andreieva, O., & Goychuk, A. (2020). Forest site conditions and the threat for insect outbreaks in the Scots pine stands of Polissya. *Folia Forestalia Polonica*, 62(4), 270-278. doi: 10.2478/ffp-2020-0026.
[3] Andreieva, O.Y., & Goychuk, A.F. (2018). Spread of scots pine stands decline in Korostyshiv forest enterprise. *Forestry and Forest Melioration*, 132, 148-154. doi: 10.33220/1026-3365.132.2018.148.
[4] Aoki, C.F., Cook, M., Dunn, J., Finley, D., Fleming, L., Yoo, R., & Ayres, M.P. (2018). Old pests in new places: Effects of stand structure and forest type on susceptibility to a bark beetle on the edge of its native range. *Forest Ecology and Management*, 419, 206-219. doi: 10.1016/j.foreco.2018.03.009.
[5] Bitvinskas, T.T. (1974). *Dendroclimatic research*. L.: Gidrometeoizdat.
[6] Bretfeld, M., Doerner, J.P., & Franklin, S.B. (2015). Radial growth response and vegetative sprouting of aspen following release from competition due to insect-induced conifer mortality. *Forest Ecology and Management*, 347, 96-106. doi: 10.1016/j.foreco.2015.03.006.
[7] Carter, D.R., Bialecki, M.B., Windmuller-Campione, M., Seymour, R.S., Weiskittel, A., & Altman, Ja. (2021). Detecting growth releases of mature retention trees in response to small-scale gap disturbances of known dates in natural-disturbance-based silvicultural systems in Maine. *Forest Ecology and Management*, 502, article number 119721. doi: 10.1016/j.foreco.2021.119721.
[8] Cook, E.R, & Kairiukstis, L.A. (1990). *Methods of dendrochronology – applications in the environmental sciences*. Dordrecht: Kluwer Academic Publishers and International Institute for Applied Systems Analysis.
[9] Cregg, B.M., Dougherty, P.M., & Hennessey, T.C. (1988). Growth and wood quality of young loblolly pine trees in relation to stand density and climatic factors. *Canadian Journal of Forest Research*, 18(7), 851-858. doi: 10.1139/x88-131.

[10] Danneyrolles, V., Dupuis, S., Fortin G., Leroyer, M., de Römer, A., Terrail, R., Vellend, M., Boucher, Ya., Laflamme, J., Bergeron, Y., & Arseneault, D. (2019). Stronger influence of anthropogenic disturbance than climate change on century-scale compositional changes in northern forests. *Nature Communications*, 10, article number 1265. doi: 10.1038/s41467-019-09265-z.
[11] Elferts, D. (2007). Scots pine pointer-years in northwestern Latvia and their relationship with climatic factors. *Biology. Acta Universitatis Latviensis*, 723, 163-170.
[12] Frelich, L.E., Montgomery, R.A., & Reich, P.B. (2021). Seven ways a warming climate can kill the southern boreal forest. *Forests*, 12(5), number article 560. doi: 10.3390/f12050560.
[13] Fritts, H.C. (1976). *Tree ring and climate*. London: Academic Press.
[14] Guehl, J.M., Clement, A., Kaushal, P., & Aussenac, G. (1993). Planting stress, water status and non-structural carbohydrate concentrations in Corsican pine seedlings. *Tree Physiology*, 12, 173-183. doi: 10.1093/treephys/12.2.173.
[15] Holmes, R.L. (1983). Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin*, 43, 69-78.
[16] Huang, X., Dai, D., Xiang, Ya., Yan, Zha., Teng, M., Wang, P., Zhou, Zhi., Zeng, L., & Xiao, W. (2021). Radial growth of Pinus massoniana is influenced by temperature, precipitation, and site conditions on the regional scale: A meta-analysis based on tree-ring width index. *Ecological Indicators,* 126, article number 107659. doi: 10.1016/j.ecolind.2021.107659.
[17] Izworska, K., Muter, E., Fleischer, P., & Zielonka, T. (2022). Delay of growth release after a windthrow event and climate response in a light-demanding species (*European larch Larix decidua Mill.*). *Trees*, 36(1), 427-438. doi: 10.1007/s00468-021-02218-4.
[18] Kern, C.C., Burton, Ju.I., Raymond, P., D'Amato, A.W., Keeton, W.S., Royo, A.R., Walters, M.B., Webster, Ch.R., & Willis, J.L. (2017). Challenges facing gap-based silviculture and possible solutions for mesic northern forests in North America, Forestry. *An International Journal of Forest Research*, 90(1), 4-17. doi: 10.1093/forestry/cpw024.
[19] Kipfmueller, K.F., Montpellie, E.E., Trumper, M.L., & Griffin, D. (2022). Intra-annual ring width and climate response of red pine in Itasca State Park in north-central Minnesota. *Canadian Journal of Forest Research*, 52(5), 870-881. doi: 10.1139/cjfr-2021-0210.
[20] Koval, I. (2020). Radial growth of *Quercus robur* L. response to climate change in Polissya and Forest-Steppe. *Proceedings of the Forestry Academy of Sciences of Ukraine*, 20, 64-73. doi: 10.15421/412006.
[21] Koval, I.M., & Voronin, V.O. (2019). Dendroclimatology as the part of dendrochronology. *Man and Environment. Issues of Neoecology*, 32, 85-94. doi: 10.26565/1992-4224-2019-32-07.
[22] Kraj, W., Szewczyk, G., Zarek, M., Wąsik, R., & Bednarz, B. (2022). Radial growth response of *Pinus sylvestris* L. and *Fagus sylvatica* L. to technological solutions applied in rope climbing park. *Dendrochronology*, 76, article number 126000. doi: 10.1016/j.dendro.2022.126000.
[23] Lebourgeois, F. (2000). Climatic signals in earlywood, latewood and total ring width of Corsican pine from western France. *Annals of Forest Science*, 57(2), 55-164. doi: 10.1051/forest:2000166.
[24] Meshkova, V. (2021). The lessons of scots pine forest decline in Ukraine. *Environmental Sciences Proceedings,* 3, article number 28. doi: 10.3390/IECF2020-07990.
[25] Meshkova, V., Borysenko, O., & Pryhornytskyi, V. (2018). Forest site conditions and other features of scot's pine stands favorable for bark beetles. *Proceedings of the Forestry Academy of Sciences of Ukraine*, 16, 106-114. doi: 10.15421/411812.
[26] Moral, F.J., Rebollo, F.J., Paniagua, L.L., García-Martín, A., & Honorio, F. (2016). Spatial distribution and comparison of aridity indices in Extremadura, southwestern Spain. *Theoretical and Applied Climatology*, 126, 801-814. doi: 10.1007/s00704-015-1615-7.
[27] Radaković, N., & Stajić, B. (2021). Climate signals in earlywood, latewood and tree-ring width chronologies of sessile oak (*Quercus petraea* (Matt.) Liebl.) from Majdanpek, North-Eastern Serbia. *Drvna Industrij*a, 72(1), 79-87. doi: 10.5552/drvind.2021.2016.
[28] Siitonen, J. (2014). *Ips acuminatus* kills pines in southern Finland. *Silva Fennic*a, 48, article number 1145. doi: 10.14214/sf.1145.
[29] Soulé, P.T., Knapp, P., Paul, A., Maxwell, T., Tyler, J., & Mitchell, J. (2021). A comparison of the climate response of longleaf pine (*Pinus palustris* Mill.) trees among standardized measures of earlywood, latewood, adjusted latewood, and total wood radial growth. *Trees*, 35, 1065-1074. doi: 10.1007/s00468-021-02093-z.
[30] Sun, S., Zhang, J., Zhou, J., Guan, C., Lei, S., Meng, P., & Yin, C. (2021). Long-term effects of climate and competition on radial growth, recovery, and resistance in Mongolian. *Frontiers in Plant Science*, 12, article number 729935. doi: 10.3389/fpls.2021.729935.
[31] Venegas-González, A., Gibson-Capintero, S., Anholetto-Junior, C., Mathiasen, P., Premoli, A.C., & Fresia, P. (2022). Tree-ring analysis and genetic associations help to understand drought sensitivity in the Chilean endemic forest of nothofagus macrocarpa. *Frontiers in Forests and Global Change*, 5, article number 762347. doi: 10.3389/ffgc.2022.762347.

Рання та пізня деревина сосни звичайної в умовах різного ступеню освітлення

Олена Юріївна Андреєва[1], Ірина Михайлівна Коваль[2], Віталій Олександрович Смолін[3]

[1]Поліський національний університет
10008, б-р Старий, 7, м. Житомир, Україна

[2]Український науково-дослідний інститут лісового господарства
та агролісомеліорації ім. Г.М. Висоцького
61024, вул. Пушкінська, 86, м. Харків, Україна

[3]Національний університет біоресурсів і природокористування України
03041, вул. Генерала Родимцева, 19, м. Київ, Україна

Анотація. Стан соснових насаджень в Поліссі погіршується у зв'язку зі збільшенням кількості спалахів верхівкового короїда (*Ips acuminatus*) на тлі зміни клімату, тому актуальність цієї проблеми не викликає сумнівів. Мета дослідження – виявлення особливостей динаміки пізньої та ранньої деревини сосни звичайної (*Pinus Sylvestris* L.) на ділянках із різним ступенем освітлення після суцільної рубки в осередках верхівкового короїда (*Ips acuminatus*) в Поліссі. Застосовано стандартні дендрохронологічні, дендрокліматичні та статистичні методи. Встановлено, що після суцільної рубки 2013 року на ділянках, розташованих поряд з цією рубкою, з одного боку відбулося підвищення радіального приросту сосни, бо збільшилися площі живлення та покращився режим освітлення дерев, а з іншого боку дерева, які ростуть поряд зі зрубами є ослабленими и мають крихкі керни, що свідчить про втрату якості деревини. Після рубки, упродовж 2014–2020 рр. перевищення середніх величин шарів пізньої деревини сосни для дерев освітлених тимчасових пробних площ порівняно з відповідними величинами на контролі становили 43–45%. Для ранньої деревини ці величини коливалися в межах 38–42%. Індекси зміни приросту показали, що після рубки 2013 року порушення відбулися для дерев на освітлених тимчасових пробних площах на відміну від контролю. Найбільш чутливими до кліматичних чинників виявилися деревно-кільцеві хронології пізньої деревини на найбільш освітленій тимчасовій пробній площі. Встановлено підвищення чутливості радіального приросту сосни в залежності від збільшення ступеню освітлення. Про ослаблення насадження на найбільш освітленій ділянці свідчить те, що для деревно-кільцевої хронології ранньої та пізньої деревини виявлено найбільшу кількість значущів взаємозв'язків між приростом та кліматом, при цьому критичного зниження трендів шарів пізньої та ранньої деревини не відбулося. Результати досліджень можна використати для планування лісогосподарських заходів

Ключові слова: *Pinus sylvestris* L., *Ips acuminatus*, деревно-кільцеві хронології ранньої та пізньої деревини, суцільна рубка, індекси зміни приросту, кліматичні чинники