UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 16(4)

UDC 630

Publisher:
National University of Life and Environmental Sciences of Ukraine

Year of foundation: 2010
Frequency of issue: Four times per year

Recommended for printing and distribution
via the Internet by the Academic Council
of National University of Life and Environmental Sciences of Ukraine
(Minutes No. 5 of 27 November, 2025)

State Registration:
Media identifier R30-02293.
Decision of the National Council
of Television and Radio Broadcasting of Ukraine
No. 1795, Minutes No. 31, dated 21.12.2023.

The journal is included in the list of professional publications of Ukraine
Category "B". Specialities:
0812 – Horticulture, 0821 – Forestry, 0722 – Materials (Paper and Wood),
0521 – Environmental Sciences, 0511 – Biology
(Order of the Ministry of Education and Science of Ukraine No. 1693, dated December 23, 2025)

The journal is presented international scientometric databases,
repositories and scientific systems:
Google Scholar, Vernadsky National Library of Ukraine, BASE, CABI, AGRIS, GEOBASE, Polska Bibliografia Naukowa (PBN), Scientific Indexing Services (SIS), UCSB Library, Ulrichsweb Global Serials Directory, EBSCO, Dimensions, University of Oslo Library, University of Hull Library, SOLO – Search Oxford Libraries Online, European University Institute, Leipzig University Library, Cambridge University Library, ProQuest, OUCI (Open Ukrainian Citation Index), Worldcat, ERIH PLUS, Litmaps, COPE

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UKRAINIAN
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УДК 630

Видавець:
Національний університет біоресурсів і природокористування України

Рік заснування: 2010
Періодичність випуску: 4 рази на рік

Рекомендовано до друку та поширення
через мережу Інтернет Вченою радою
Національного університету біоресурсів і природокористування України
(протокол № 5 від 27 листопада 2025 р.)

Державна реєстрація:
Ідентифікатор медіа R30-02293.
Рішення Національної Ради України
з питань телебачення і радіомовлення
№ 1795, протокол № 31 від 21.12.2023 р.

Журнал входить до переліку фахових видань України
Категорія «Б». Спеціальності:
E2 (101) – Екологія, E1 (91) – Біологія та біохімія, H3 (206) – Садово-паркове господарство,
H4 (205) – Лісове господарство, G14 (187) – Деревообробні і меблеві технології
(наказ Міністерства освіти і науки України № 1693 від 23 грудня 2025 року)

Журнал представлено у міжнародних наукометричних базах даних,
репозитаріях та пошукових системах:
Google Scholar, Національна бібліотека України імені В. І. Вернадського, BASE, CABI, AGRIS, GEOBASE, Polska Bibliografia Naukowa (PBN), Scientific Indexing Services (SIS), UCSB Library, Ulrichsweb Global Serials Directory, EBSCO, Dimensions, University of Oslo Library, University of Hull Library, SOLO – Search Oxford Libraries Online, European University Institute, Leipzig University Library, Cambridge University Library, ProQuest,
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Адреса редакції:
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Received: 27.06.2025; Revised: 30.09.2025; Accepted: 27.11.2025

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 16(4)

UDC 551.583: 4.630*55
DOI: 10.31548/forest/4.2025.08

Dendrochronological assessment of climate risks for the restoration of oak forests in the Ukrainian Polissya

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Abstract. The deterioration of climatic conditions caused by global warming poses a threat to the sustainable development of forest ecosystems, particularly oak stands, which are an important component of Ukraine's forestry sector. The purpose of the study was to determine the growth responses of *Quercus robur* L. trees to long-term climatic changes leading to increased aridity in the conditions of the Ukrainian Polissya. The gradients of the temperate climate in the locations where *Quercus robur* L. trees grow in Ukraine were analysed, namely the climatic factors (extreme temperatures, precipitation) that affect the growth and development of trees on a monthly and seasonal time scale. The results provide important information on the regional prospects for

Suggested Citation:
Oliynyk, R., Vasylyshyn, R., Pinchevska, O., & Spirochkin, A. (2025). Dendrochronological assessment of climate risks for the restoration of oak forests in the Ukrainian Polissya . *Ukrainian Journal of Forest and Wood Science*, 16(4), 8-30. doi: 10.31548/forest/4.2025.08.

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growing oak plantations in Ukraine. Random climatic factors, which act synergistically with systemic factors, negatively affect tree growth, regardless of the characteristics of the forest management system. The influence of climatic conditions on the radial growth of *Quercus robur* L. trees within their natural range was studied. Particular attention was paid to situations where the analysed trees formed rings whose width exceeded the interval – the mean plus or minus the standard deviation ($\bar{R} \pm SD$). Chronologies of climatic signals covering the new reference period 1991-2020 were developed for the studied locations. Simple indices of extreme monthly average air temperatures and monthly precipitation indices were calculated. A climatic analysis was conducted for the years in which anomalies in the growth of *Quercus robur* L. trees were observed, identified by the tree ring width index (TRWI). It has been established that annual precipitation totals and maximum air temperatures in the spring-summer season have a statistically significant impact on radial growth. The constructed polynomial models allow predicting changes in the growth dynamics of *Quercus robur* L. trees for the studied region

Keywords: climate change; climate signals; dendrochronological analysis; tree ring width; ring width index

Introduction

In light of predicted climate change, there is a need to assess the impact of future climate gradients on the growth, development and distribution of tree species. The resilience of species to climate change is of significant importance for forecasting the development of forest management systems (IPCC, 2022). Dendrological research has been conducted mainly in two areas: tree growth dynamics in their natural habitat and their response to climate change, and tree growth characteristics in warm, dry regions that currently exhibit the climatic conditions expected in the future climate for a given locality. However, unfavourable climatic conditions are not the only cause of plant growth disruption, as there are other causes, according to A. Wallraf & S. Wagner (2019). The distribution range of a species is determined not only by climate, as there are a number of systemic factors, including latent ones, that affect the growth of woody plants. The suppression and even displacement of a particular species can occur due to the presence of competing species that are better adapted to the area. The authors A. Wallraf & S. Wagner suggested that any statistical correlations between climatic conditions and growth indicators may be questionable in terms of cause-and-effect relationships.

Nevertheless, M. Steckel *et al.* (2020) believed that climatic gradients, which are entirely random in nature, have both a direct and indirect impact on tree growth and development, as rising temperatures accelerate chemical reactions that release nutrients, enhancing the growth of trees and microbial populations, while reducing humidity and stimulating soil droughts. The impact of climatic stresses on the common oak (*Quercus robur L.*) in the forest-steppe zone of Ukraine, studied by I.M. Koval & A. Bräuning (2024), causes noticeable reactions in the radial growth of trees to climate variations. Depressions in radial tree growth were observed in years with low precipitation and elevated ground temperatures, while maximum growth was observed in years with favourable temperature and humidity conditions for tree growth. A study by R. Puchałka *et al.* (2024)

of *Quercus petraea* within its natural range in northern Poland showed that there is currently a trend towards a decline in the viability of mature trees and a reduction in their radial growth, despite the fact that climatic conditions for this species remain stable. This is evidenced by observations of the species' cambial activity during growing seasons in years with negative and positive water balances. This enabled the authors R. Puchalka *et al.* to compare the phases of wood formation and growth width. They found that in dry years, cambial activity ceased earlier than in wet years, and that precipitation significantly prolonged the duration of cambial activity and contributed to the formation of wide rings. Late spring frosts (LSF) are increasingly being added to the list of anomalies in the modern regional climate.

E. Tonelli *et al.* (2022) investigated the negative impact of late spring frosts on tree productivity and growth in temperate forests. The reduction in growth of trees affected by LSF ranged from 36 to 84%. The negative impact was only observed during the year when LSFs were fixed, with growth recovery occurring within 1-2 years after the event. However, detailed information on how these forests recover after such events is still not available. According to the authors, the increase in the frequency of LSF may, in the long term, threaten the disappearance of certain species, in particular the presence of beech in the high-altitude forests of the Mediterranean. There is a deficit of research on tree growth in conditions that differ significantly from those of their natural habitat. Therefore, the study by D. Moreno-Fernandez *et al.* (2022) on forests in central Spain is extremely relevant, as it can provide insight into how native species will grow in new climatic conditions. The authors of the study connected the process of pine forest dieback observed in 2019 with rapidly changing climatic conditions and drought stress.

The limitation of the mentioned approaches is that the actual adaptation of tree species to climatic conditions has not yet been fully understood. The Polissya region of Ukraine is characterised by a temperate climate, where forest formation has been ongoing for over a millennium. There is a need to predict their productivity in the context of progressive climate change. I. Ivanyuk & T. Ivanyuk (2019) noted that over the last decade, significant fluctuations in the radial growth index of common oak have been observed in the Ukrainian Polissya, indicating the species' response to climatic signals. Despite the relatively high drought resistance of *Quercus robur L.* in its natural range, there is a need for further research into the climatic growth potential of trees of this species and the possibility of expanding their geographical range beyond their natural range.

The problem facing dendroclimatologists today is to correctly identify the climatic signal that has found an accessible response in tree layer data and to distinguish this signal from ground noise. The aim of the study was to investigate the influence of climatic gradients on the radial growth of *Quercus robur L.* trees in the Ukrainian Polissya. To achieve this goal, the following tasks were set: to determine annual anomalies in tree growth by calculating the tree ring width index (TRWI); to calculate climate indices on a monthly/seasonal averaging time scale; to establish a stochastic relationship between radial growth and climate signals.

The scientific novelty lies in determining the possibilities of predicting the growth dynamics of *Quercus robur L.* within its natural range, taking into account regional climate changes caused by global warming.

Materials and Methods

Three locations were studied in Ukrainian Polissya (Korosten – SITE 1; Zhytomyr –

SITE 2; Kyiv – SITE 3 and one in the Left Bank Forest-Steppe zone (Kharkiv – SITE 4), where the most common plantations involve the common oak (*Quercus robur L.)*. The main characteristics of the studied locations are presented in Table 1.

Table 1. Overview of researched sites

Location	**Geographical coordinates**		**Altitude above sea level, m**	**Climate**	**Soil types**
	Latitude, N	**Longitude, E**			
SITE1	50.97	28.61	170	Moderately continental	sod-podzolic, sod
SITE2	50.25	28.66	220	Humid moderately continental	sod-podzolic gleyed
SITE3	50.45	30.52	170	Moderately continental	gray podzolised forest
SITE4	50.06	36.35	150	Moderately continental	typical chernozems and podzolised chernozems

Source: developed by the authors

Standardisations of random meteorological series was necessary for statistical comparisons of random variables of different physical nature. For the analysis, a climate signal was used, which is a random variable, Δx, and at any given moment represents a random meteorological quantity (temperature, precipitation), the cantered value of which, x, takes specific values with a certain probability:

$$\Delta x = x - \bar{x}, \tag{1}$$

where $\bar{x}$ – is the climatic norm.

If the cantered values of meteorological variables are stabilised by dispersion, obtain dimensionless standardised values x_{st}:

$$x_{st} = \Delta x / \sigma. \tag{2}$$

In this study, standardised values of extreme monthly average air temperatures and monthly precipitation totals were considered as climate signals. Meteorological information was obtained for all study sites from the Sectoral State Archive of Hydrometeorological Observations of the State Emergency Service of Ukraine (United Hydrometeorological Station Kyiv, n.d.). The study period covered the period from 1931 to 2020 inclusive. The initial meteorological data were taken into account: daily values of maximum/minimum surface air temperature and monthly precipitation totals. The time series of annual tree ring widths at the respective sites were borrowed from scientific works (Procopuk, 2017; Ivanyuk & Fuchylo, 2020; Koval & Bräuning, 2024).

The change in the width of the annual ring, according to the law of tree ring growth, is determined by the following formula, obtained from the equation given in the work (Giraldo & Dell Valle, 2016):

$$TRW = \frac{C_1 e^{-\alpha_1 t} + C_2 e^{-\alpha_2 t}}{3C_3 \sqrt[3]{\rho (C_4 + C_1 e^{-\alpha_1 t} + C_2 e^{-\alpha_2 t})^2}}, \tag{3}$$

where C_1, C_2, C_3, C_4 – some coefficients; α_1, α_2 – positive constants; ρ – wood density.

The appearance of the function of the change in the width of the annual ring as the tree grows is shown in Figure 1.

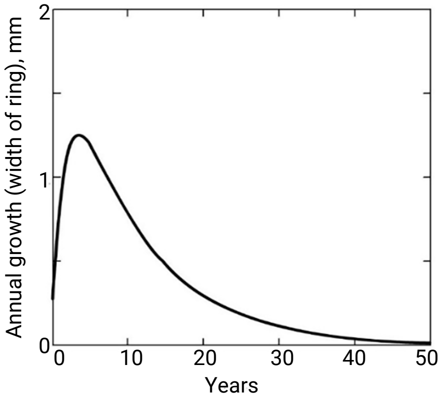


Figure 1. A typical form of the function of the wood ring width (with an increase in the width of wood ring at initial stage)
Source: J.A. Giraldo & J.I. Dell Valle (2016)

Thus, the presented analytical dependence (3) and its graphical interpretation (Fig. 3) describe the general law of tree-ring width variation over time. This relationship forms the theoretical basis for further statistical analysis and standardisation of the obtained dendrochronological series.

Applied statistical analysis of time series of meteorological variables and ring width series was performed using STATISTICA (version 12), which, in particular, allowed for detailed investigation of: graphical representation and analysis of time series behaviour; identification of deterministic components of the series; removal of low- or high-frequency components of the series; random component of the time series; prediction of the behavior of the time series.

Results

The results of calculations for the Zhytomyr region are shown in Figure 2.

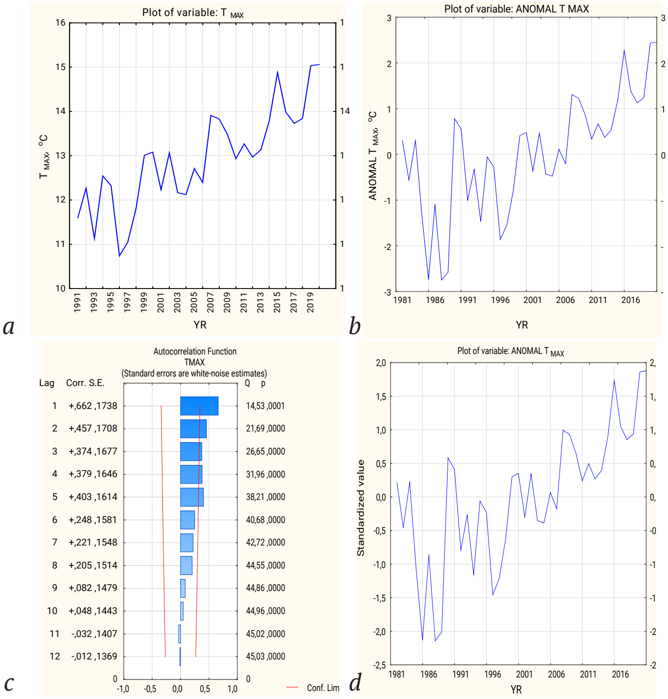
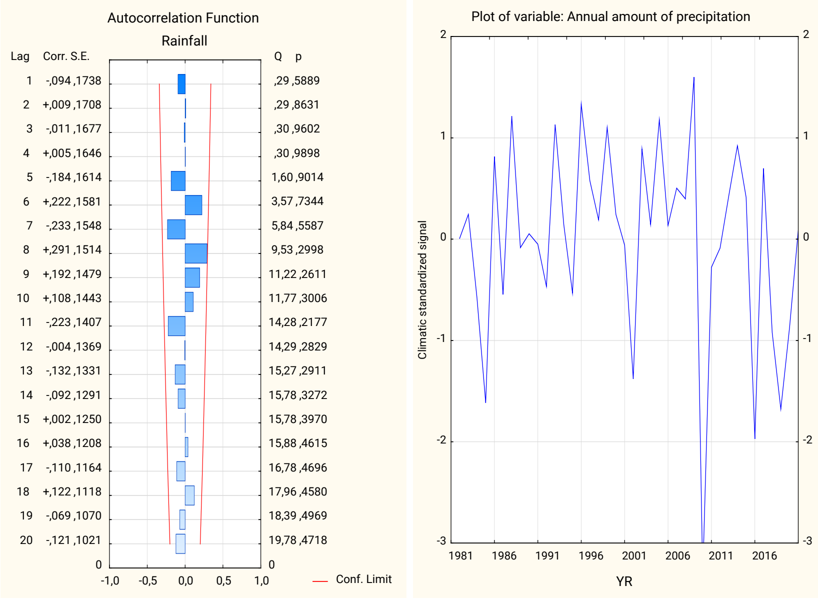


Figure 2. Growth trends of the surface maximum air temperature chronologies (SITE 2)
Note: a – original unprocessed series; b – cantered series; c – autocorrelation function; d – standardised series (climatic signal)
Source: compiled by the authors

The dynamics of annual extreme temperature variability indicate the presence of a linear trend in the random process, which has a steady tendency to increase the maximum temperature (Fig. 2a). Climatological anomalies, according to the recommendations of the World Meteorological Organisation (WMO, n.d.), are determined by centred values relative to the climatic norm (Fig. 2b). The downward trend of the correlation function of the time series of the random component (Fig. 2c) indicates that the process is stationary, i.e., the mean value and variance have become stable, which allows us to move to standardised values of the random component, which acquires the meaning of a climate dimensionless signal (Fig. 2d).

The dynamics of annual precipitation variability for all locations shows a slightly expressed linear downward trend. The tendency towards a decrease in annual precipitation is observed at a level of < 1 mm/yr (Fig. 3). The process proved to be stationary, as evidenced by the downward nature of the correlation function. Therefore, this allows to immediately proceed to the standardisation of the initial series of annual and monthly precipitation totals.



a *b*

Figure 3. Standardised climate signal - annual amounts of precipitation (SITE 2)
Note: a – autocorrelation function rainfall; b – dynamics of climatic standardised signal
Source: compiled by the authors

If examine the width of the ring without taking into account the initial growth phase, the dynamics of the ring width can be satisfactorily approximated by a negative exponential function. Thus, in order to transition to standardised tree ring width index (TRWI) values, it is necessary to decompose the time series, i.e. to convert the non-stationary TRW time series into a stationary one by removing seasonality and trend from it. Depending on the age of the tree, as well as the initial conditions, the trend takes on a slightly different form (Fig. 4), since the dendrological process is non-stationary.

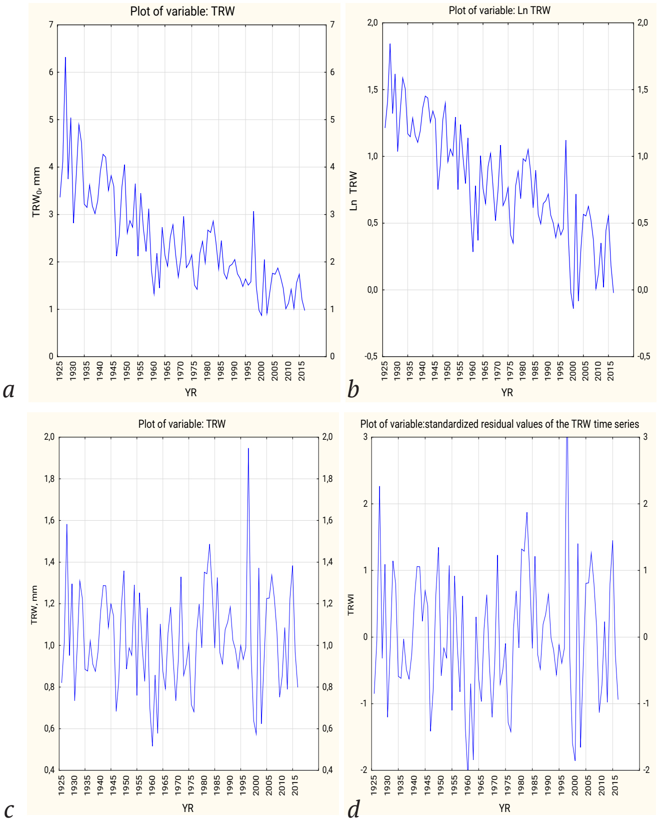


Figure 4. The sequence of standardisation of the width of the wood ring SITE 4
Note: a – original series of data TRW; b – linearisation of the original series by logarithmisation; c – decomposed data series TRW; d – wood ring width index TRWI
Source: compiled by the authors

The study of the correlation function of long TRW series, including the initial growth stage, shows its relative stability. Therefore, there is a need to convert the random process into a stationary mode, i.e. it is necessary to remove the trend. If use the dendrochronological equation (3), a complex task of its parameterisation arises, so applied a statistical approach to remove the trend, which gives satisfactory results provided that the initial sample is sufficient. Since the trend TRW_0 decreases according to the exponential law (Fig 4a), the initial series was logarithmised for its linearisation (Fig. 4b). After removing the linear trend, a new series was formed, the TRW residual series (Fig. 4c), which contains only a random component. The stationarity of the new series allows it to be presented in a standardised form (Fig. 4d) and considered as a series of the TRWI tree ring width index.

Annual climate anomalies and TRWI variations. According to the recommendations of the World Meteorological Organisation (WMO, n.d.), the time lag for recording climate change should be at least 30 years. In order to organise climate information obtained from different locations, it is proposed to select reference periods starting with years ending in a unit. Meteorological data averaged over this period are considered as reference data (climatic norms) against which the climatology of the random process in the studied location is analysed for a fixed reference period. Since the evolutionary cycle of oak forest (*Quercus robur L.*), in particular, is more than a century, the question arises regarding the identification of climate anomalies, namely in relation to the reference period. Unfortunately, climate data for the locations under study have different histories. Nevertheless, it was possible to track the variability of climatic reference indicators (Table 2). The list of regional indicators of climate change includes, first of all, temperature indicators – maximum and minimum air temperatures, which determine the temperature range for a fixed location in a given time interval.

Table 2. General characteristics of test areas

Reference period	Descriptive statistics (maximum temperature. SITE1Winter.sta)						
	Valid N	Mean	Minimum	Maximum	Std.Dev.	Skewness	Kurtosis
1931-1960	78	-1.9	-9.2	5.0	3.24	-0.55	-0.27
1941-1970	66	-1.8	-10.8	5.0	3.11	-0.85	0.96
1951-1980	78	-1.5	-10.8	5.0	2.87	-0.81	1.60
1961-1990	78	-1.2	-10.8	6.1	3.08	-0.59	1.17
1971-2000	90	-0.5	-9.7	6.1	2.95	-0.55	0.77
1981-2010	90	-0.3	-9.7	7.2	3.07	-0.45	0.94
1991-2020	90	0.2	-6.8	7.2	2.92	-0.06	-0.20
2001-2024	69	0.4	-6.6	7.2	2.96	-0.11	-0.24

Source: compiled by the authors by statistical evaluation of primary data of United Hydrometeorological Station Kyiv (n.d.)

Regional responses to global warming, which began in the 1980s, have been ambiguous and unpredictable. Statistical analysis of meteorological data has revealed trends in temperature changes in the lower atmosphere at all sites studied. There is a steady trend towards an increase in both max/maximum temperature and min/minimum temperature, with the latter increasing more noticeably. It should be noted that the empirical distribution of extreme temperatures does not show a tendency towards excess and right-sided asymmetry, but rather approaches the standard Gaussian distribution.

The climatic norms of average annual (average monthly) values of extreme temperatures and annual (monthly) precipitation totals, which were determined for the studied sites, made it possible to identify climatic signals, such as anomalies in temperature and precipitation patterns relative to the climatic norm. Since the random processes under study demonstrate stationarity, by stabilising the centred values of the average annual maximum and minimum air temperatures and annual precipitation totals by dispersion, it is possible to move on to dimensionless standardised indices – IT_{MAX}, IT_{MIN}, IPR. If the corresponding climate index takes on a value $>|\pm 1|$, this means that the meteorological value is outside the interval and such an index is considered a climate signal (Fig. 5, Fig. 6). A climate signal in this format proved to be quite convenient for analysis, since not only the time of the event is identified, but also the relative weight and phase of the signal. It should be noted that the ITMAX, ITMIN and IPR signals contain trend components, since during the reference period under study, the values of climate signals change as a result of both systematic (planetary) and random (regional) factors.

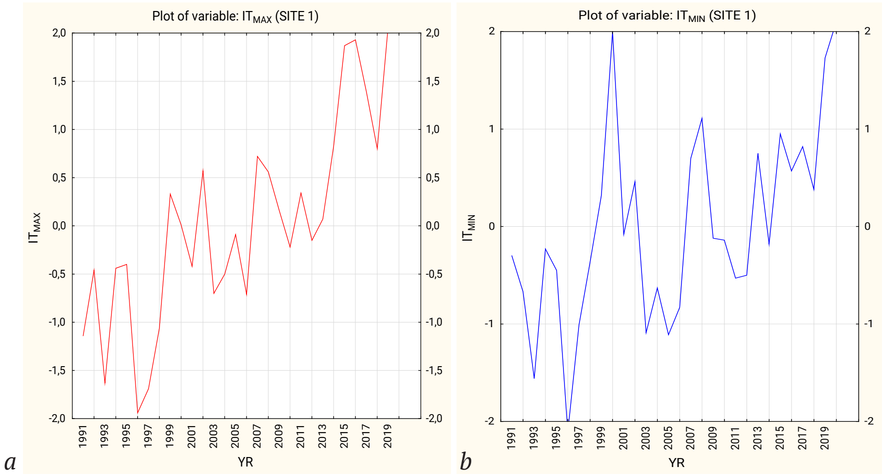


Figure 5. Dynamics of climatic temperature signals (a-ITMAX; b-ITMIN)

Source: compiled by the authors

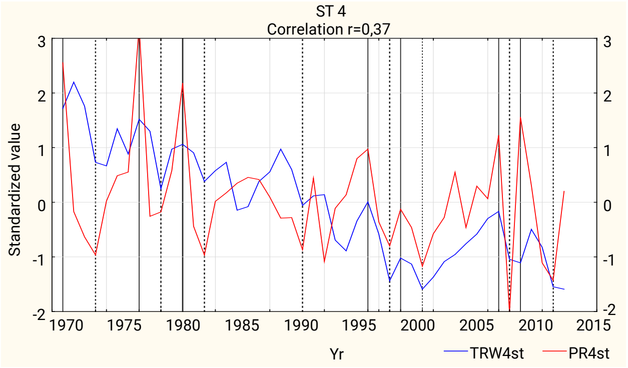


Figure 6. Dynamics of TRWI and IPR series (SITE4)

Source: compiled by the authors

To identify climate signals, input meteorological series data (maximum/minimum monthly average temperature; monthly precipitation totals) were standardised for each year of the reference period at each site. The annual values of climate signals allowed to identify anomalous years and determine the phase of the corresponding signals (Table 3).

Table 3. Anomalous years

SITE 1		**SITE 2**		**SITE 3**		**SITE 4**	
maximum surface air temperature							
✲							
1999	1991	2010	1991	1999	1993	2007	1991
2002	1992	2012	1992	2010	1994	2010	1992

Table 3, Continued

SITE 1		SITE 2		SITE 3		SITE 4	
maximum surface air temperature							
2007	1993	2014	1993	2014	1996	2012	1993
2011	1996	2015	1996		1997	2013	1994
2013	1997	2016	1997		1998	2014	1996
2015	1998		1998				1997
2016	2000		2004				2004
			2006				2006
minimum surface air temperature							
1999	1993	2007	1991	1992	1993	1995	1993
2001	1994	2008	1993	2010	1996	1999	1994
2007	1996	2010	1996		2000	2008	1996
2011	1997	2012	1997			2010	1997
2013	2000	2014	2000			2011	2003
2015	2004	2016	2004			2012	2004
	2005					2014	2005
	2006					2016	2009
annual precipitation amounts							
1997	2011	1998	1994	2002	1991	1995	1994
1998	2015	1999	1995	2005	2009	1997	1999
2010		2001	2000	2012	2015	2003	2000
2012		2007	2011	2013		2016	2017
2017		2012	2015				
		2013					
tree ring width							
2010	1996	1991	2002	2001	2003	1997	1999
2011	2000	1992	2003	2006	2009	2001	2000
2012	2001	1993	2004	2007	2010	2006	2002
2013	2002	1997	2016		2011	2014	2009
2014	2003	1998			2012		2012
2015	2004	2010			2015		

Note: * – signal decreases/increases relative to the climatic norm
Source: developed by the authors by analysis of primary of United Hydrometeorological Station Kyiv (n.d.)

Thus, only those years were identified for which the average annual maximum/minimum air temperature and/or annual precipitation in standardised values exceeded ±1, i.e. fell outside the interval . With regard to TRW, the procedure was somewhat more complicated, since the time series were first used to identify the exponential trend, after which the residuals were standardised (Fig. 6). The signal obtained in this way was represented as the tree ring width index (TRWI). Table 3 shows only those cases where TRWI > |1|. Since the probabilistic empirical distributions of the samples are satisfactorily described by the normal law, the Pearson consistency criterion was used to establish a statistical relationship between climate signals and TRWI (Table 4). Climatic and dendrological studies at the study sites allowed to identify climatic signals (ITMAX; ITMIN; IPR) for each year of the reference period (1991-2020) and establish a statistical relationship between them and TRWI, which turned out to be weak to moderate (Table 4). As expected, ITMAX and ITMIN are negatively correlated with TRWI at all sites, while IPR is positively correlated.

Table 4. Pairwise Pearson correlation between TRWI and climatic annual signal

Climatic annual signal	Correlations			
	SITE 1	SITE 2	SITE 3	SITE 4
IT_{MAX}	-0.33	-0.43	-0.45	-0.24
IT_{MIN}	-0.16	-0.31	-0.39	-0.29
IPR	+0.47	+0.35	+0.43	+0.37

Source: developed by the authors

A moderately weak correlation is likely related to noise in the useful signal. While annual precipitation totals, which have a long-term impact on tree growth, still make sense as an annual indicator, temperature indicators at a time interval (year) do not reflect the changing temperature regime during the growing season. As is known, the empirical distribution of annual temperature for a temperate continental climate is bimodal, i.e. the average annual temperature is not the mode of distribution. Thus, a climate history at the level of average monthly values for the years presented in Table 3 is needed to identify seasonal climate effects. Interpreting the response of forest growth to climate change requires an understanding of both the temporal and spatial patterns of seasonal climatic influences on growth, in particular for *Quercus robur L.*

Seasonal climate signals. During the reference period 1991-2020, correlations between annual climate signals and TRWI were found at all sites for each climate variable. The greatest influence on the growth of *Quercus robur L.* is exerted by precipitation ($r = 0.47$; $p < 0.05$) and maximum air temperature ($r = -0.45$; $p < 0.05$), which is consistent with other TRWI studies in temperate climates (Saleh *et al.* 2022). The vegetative activity of oaks begins at temperatures above 4° C, with the optimal temperature range for them varying between $t = 15°C$ and 29°C; the best temperature regime for the active growth phase ($t = 21°C$-$27°C$), while dormancy begins at temperatures below $t < 10°C$. Therefore, seasonal climatology influences the onset and duration of the active vegetation phase. Obviously, the active vegetation of *Quercus robur L.* in a temperate climate occurs in the spring-summer season.

Seasonal climate signals, as noted earlier, represent standardised values of average monthly extreme temperatures and, accordingly, monthly precipitation totals. For SITE1 and SITE4, the study period covered almost a century (1931-2024). A warming trend was observed for all seasons (Fig. 7). In particular, during this period, the average monthly maximum temperature increased by $t = 2.2°C$, and the average monthly minimum/maximum temperature by $t = 2.6°C$. The behaviour of seasonal maximum temperature values in different reference periods varied, which complicates the identification of a useful signal.

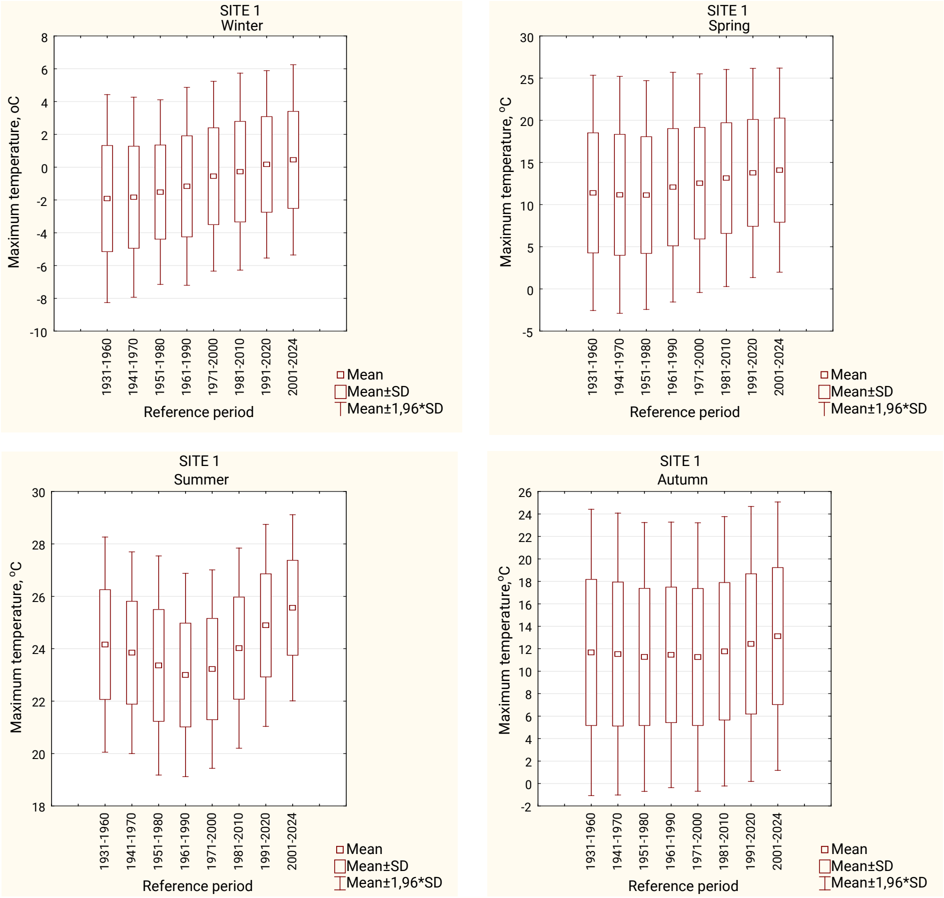


Figure 7. Average seasonal maximum temperatures for different reference periods (SITE 1)
Source: compiled by the authors

There is some ambiguity regarding precipitation. A comparison of seasonal precipitation totals for different reference periods showed: no trend in the winter-spring season; a noticeable negative trend in the summer season, with a 20% reduction in precipitation; a slight decrease in precipitation, about 7%, in the autumn season (Table 5).

Table 5. Seasonal anomalies of the precipitation regime (SITE 4)

Reference period	Climatic rate of monthly precipitation amounts, mm													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Yr**	**VegPer.**
1971-2000	30.7	29.0	33.5	46.8	49.5	90.0	100.9	65.9	58.5	34.7	43.9	39.0	622.4	386.6
1981-2010	29.3	31.8	36.5	40.4	53.7	82.3	94.0	60.8	56.3	40.6	41.7	35.8	603.2	367.7
1991-2020	31.4	34.0	41.0	38.4	61.2	70.4	82.4	53.4	47.6	42.0	39.9	38.0	579.7	346.8
2001-2024	36.8	36.7	43.3	40.7	59.6	65.1	76.8	49.5	43.5	46.9	38.7	40.8	578.4	335.0

Source: developed by the authors

If evaluate monthly precipitation amounts, there is a noticeable increase in precipitation: Feb (15%), Mar (23%), May (22%), Oct (21%); decrease in precipitation: Apr (18%), Jun (20%), Jul (18%), Aug (19%), Sep (26%), Nov (9%). Monthly precipitation totals in Dec and Jan remained stable. At the same time, the annual precipitation total has a steady downward trend at a rate of about 1 mm *yr $^{-1}$.

This study focuses on the latest reference period of 1991-2020, which, according to the recommendations of the World Meteorological Organisation (WMO, n.d.), is considered the new climate norm for the modern climate. Accordingly, seasonal and monthly climate signals are considered as relative variations with respect to the average values for the last thirty-year reference period. Monthly values of IT_{MAX}, IT_{MIN}, and IPR were determined at all sites, which made it possible to identify anomalous months and seasons that potentially affected tree ring width. Based on monthly precipitation totals, seasonal precipitation indices were formed for which correlation statistical relationships with TRWI were determined (Table 6).

Table 6. Correlation matrix TRWI-IPR SEASON

	IPR WIN	IPR SPR	IPR SUM	IPR AUT
SITE 1	**0.43**	0.12	**0.29**	-0.03
SITE 2	-0.08	**0.26**	**0.32**	-0.05
SITE 3	0.03	**0.28**	**0.26**	0.23
SITE 4	0.04	**0.39**	**0.42**	0.20

Source: developed by the authors

The statistical correlation between TRWI and seasonal climate signals IPR-SEASON (Table 6) was significantly lower at all sites than with annual climate signals, as precipitation can have a cumulative effect on growth. A comparison of the phases of climate signals was carried out separately for the spring, summer and spring-summer seasons. The expected result was a coincidence of the TRWI and IPR phases and a counterphase of TRWI and IT-MAX. However, there are a number of cases where the behaviour of TRWI and the seasonal climate signal is unclear (Table 7). For example, SITE 1: 1991 year. IPR SPR = 1.38; IPR SUM = 0.93; TRWI and 2016 year – IPR SPR = 1.17; IPR SUM = 0.81; TRWI ↑. The behaviour of climate indices is almost the same, but TRWI changes phase. Similarly, SITE 2: 2012 year. IPR SPR = 1.09; IPR SUM = 1.22; TRWI ↓. It was possible to partially explain cases where seasonal precipitation amounts increase and TRWI decreases by using information about IPR for the previous year. Since the temperature and humidity regime determines the effectiveness of the vegetation process, it is necessary to simultaneously use temperature climate signals (Table 7). The synergy of the two factors depends significantly on both the phase of the climatic signals and their seasonality.

$$TRW = 1.143 - 0.308 \cdot IT_{MAX}\,SPR + 0.218 \cdot IT^{2}_{MAX} - 0.010 \cdot IT^{4}_{MAX}. \qquad (4)$$

Table 7. Spring-summer seasonal climate indices in years of anomalies TRWI

Seasonal standardised values of maximum and minimum air temperatures											
SITE 1			SITE 2			SITE 3			SITE 4		
YR/ Phase TRWI	*Climatic season*		YR/ Phase TRWI	*Climatic season*		YR/ Phase TRWI	*Climatic season*		YR/ Phase TRWI SPR	*Climatic season*	
	SPR	SUM		SPR	SUM		SPR	SUM		SUM	
1991 ↑	1.38	0.93	1991 ↑	1.03	1.16	2001 ↑	1.28	0.88	1997 ↑	1.61	1.15

Table 7, Continued

Seasonal standardised values of maximum and minimum air temperatures											
SITE 1			SITE 2			SITE 3			SITE 4		
YR/ Phase TRWI	Climatic season		YR/ Phase TRWI	Climatic season		YR/ Phase TRWI	Climatic season		YR/ Phase TRWI SPR	Climatic season	
	SPR	SUM		SPR	SUM		SPR	SUM		SUM	
1992 ↑	1.19	0.59	1993 ↑	0.75	1.37	2003 ↓	0.67	0.88	1999 ↓	0.70	0.62
1993 ↑	0.72	1.39	1994 ↑	1.16	1.37	2006 ↑	1.51	1.21	2000 ↓	1.00	0.46
1997 ↑	0.81	1.69	1997 ↑	0.78	1.65	2007 ↑	0.49	1.47	2001 ↑	1.12	0.97
1998 ↑	1.28	1.50	1998 ↑	1.27	1.19	2009 ↓	0.63	1.23	2002 ↓	0.70	0.99
2002 ↓	0.67	1.05	2000 ↓	1.10	0.50	2010 ↓	0.79	0.77	2009 ↓	1.02	0.69
2003 ↓	0.63	0.91	2003 ↓	0.44	0.81	2011 ↓	0.38	1.71	2012 ↓	0.64	0.87
2004 ↓	0.81	0.89	2004 ↓	0.72	1.12	2012 ↓	1.09	1.22	2014 ↑	0.86	1.40
2010 ↑	0.99	1.15	2015 ↓	0.85	0.37	2015 ↓	0.91	0.34	2016 ↓	0.80	0.42
2016 ↓	1.17	0.81	2016 ↓	1.10	0.52						
Seasonal precipitation standardised values											
SITE 1			SITE 2			SITE 3			SITE 4		
YR/ Phase TRWI	Climatic season		YR/ Phase TRWI	Climatic season		YR/ Phase TRWI	Climatic season		YR/ Phase TRWI SPR	Climatic season	
	SPR	SUM		SPR	SUM		SPR	SUM		SUM	
1991 ↑	1.38	0.93	1991 ↑	1.03	1.16	2001 ↑	1.28	0.88	1997 ↑	1.61	1.15
1992 ↑	1.19	0.59	1993 ↑	0.75	1.37	2003 ↓	0.67	0.88	1999 ↓	0.70	0.62
1993 ↑	0.72	1.39	1994 ↑	1.16	1.37	2006 ↑	1.51	1.21	2000 ↓	1.00	0.46
1997 ↑	0.81	1.69	1997 ↑	0.78	1.65	2007 ↑	0.49	1.47	2001 ↑	1.12	0.97
1998 ↑	1.28	1.50	1998 ↑	1.27	1.19	2009 ↓	0.63	1.23	2002 ↓	0.70	0.99
2002 ↓	0.67	1.05	2000 ↓	1.10	0.50	2010 ↓	0.79	0.77	2009 ↓	1.02	0.69
2003 ↓	0.63	0.91	2003 ↓	0.44	0.81	2011 ↓	0.38	1.71	2012 ↓	0.64	0.87
2004 ↓	0.81	0.89	2004 ↓	0.72	1.12	2012 ↓	1.09	1.22	2014 ↑	0.86	1.40
2010 ↑	0.99	1.15	2015 ↓	0.85	0.37	2015 ↓	0.91	0.34	2016 ↓	0.80	0.42
2016 ↓	1.17	0.81	2016 ↓	1.10	0.52						

Source: developed by the authors

Modelling. The annual change in ring width is a non-stationary process. If consider the early growth period (Fig. 8), the trend appears to be complex. The variability of climatic signals was found to be close to a stationary process, with a linear increasing temperature trend and a decreasing precipitation trend. Nevertheless, such processes can be described by nonlinear regression modelling, namely polynomial models, since the trend-cyclical component of the factors experiences several local extrema. The task of building a model can be significantly simplified if consider separate periods of tree evolution. In particular, as already noted, this study focuses on the period 1991-2020. Since the objects of the study were groups of trees in the age category of over 60 years, the specified period falls on the right wing of the ring width growth curve, which is satisfactorily approximated by an exponential downward law. As noted earlier (Table 4), the correlation between TRWI and the annual IT_{MAX} index at SITE 4 was weak (-0.29). However, when switching to the seasonal time interval, the correlation increased significantly, as it was possible to identify a useful signal (Table 6). The polynomial regression model of TRW by the influencing factor – the average maximum air temperature in the spring season IT_{MAX} SPR (4) – proved to be adequate with statistically significant regression coefficients (Table 8):

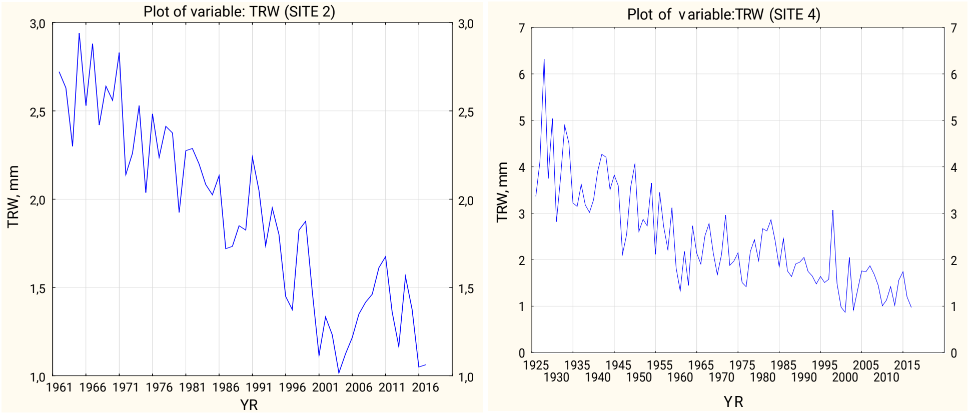


Figure 8. Dynamics of the width of the tree ring

Source: compiled by the authors

Table 8. Regression summary for dependent variable TRW. SITE 4

N = 35	TRW (SITE 4 IT_{MAX} SPRING. sta) R = 0.764; R2 = 0.585; F(3.31) = 6.932; p < 0.0002					
	b*	**Std.Err. of b***	**b**	**Std.Err. of b**	**t (31)**	**p-value**
Intercept			1.142796	0.107829	14.30783	0.000000
IT_{MAX} SPR	-1.01692	0.242777	-0.308296	0.073602	-4.18869	0.000216
IT^2_{MAX} SPR	2.19228	0.621667	0.217752	0.061748	3.52646	0.001335
IT^4_{MAX} SPR	-2.45314	0.667909	-0.010039	0.002733	-3.67287	0.000899

Source: developed by the authors

The results of the analysis (Table 8) show that the multiple correlation between TRW and predictors is strong (R > 0.75); the model adequately describes the relationship between response and predictors, and the free term is statistically significant (p < 0.0000). Standardised regression coefficients (b*) allow to compare the contributions of each predictor to the prediction of the response. The predictor IT^4_{MAX} SPR has the greatest influence, which has a minus sign in the model, i.e. regardless of the phase of this signal, it is always negative, which ensures a downward trend. Model (4) adequately describes the variations in TRW in the studied interval, and the model curve practically repeats the behaviour of the original series (Fig. 9a).

To analyse the adequacy of the model, examined the residuals, which represent the difference between the actual TRW values and those predicted by the model. Visualisation of the residuals using a histogram shows (Fig. 9b) that the sample density of their distribution is successfully approximated by a normal distribution, which is a sign of the adequacy of the constructed TRW model. The graph of the residuals (Fig. 9c) allows to track their variation throughout the entire time series and ensure that there is no obvious trend. In a correctly selected model, the residuals should approach "white noise": they have no periodic fluctuations, systematic shifts, or strong correlations. The autocorrelation function graph (Fig. 9d) confirms that the residuals are practically 'white noise'.

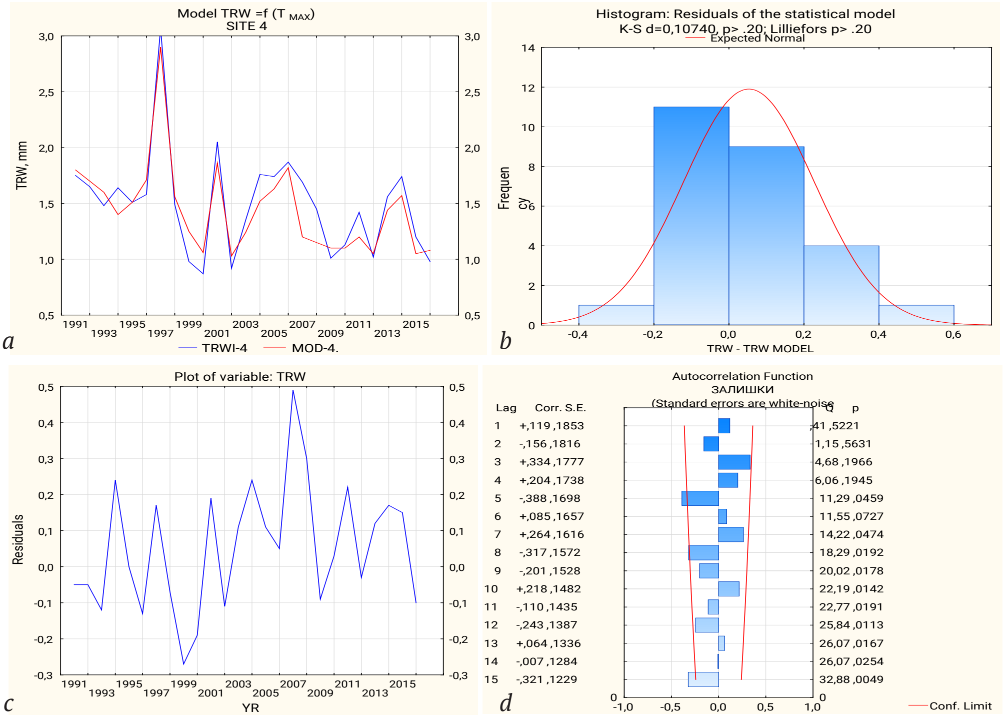


Figure 9. Polynomial model TRW – ITMAX SPR (SITE 4)
Note: a – TRW dynamics; b – empirical law of residual distribution; c – TRW residual dynamics; d – autocorrelation function of residuals
Source: compiled by the authors

It was not possible to develop an adequate polynomial model that would simultaneously combine temperature and humidity characteristics with TRWI, since anomalies in monthly precipitation totals and maximum temperatures were observed in different seasons of the year. However, it was possible to construct an adequate statistical regression model of TRWI-IPR YR. The correlation between the annual precipitation index (IPR YR) and the TRWI response was moderate (Table 4)**.** The clear dependence between the studied series allowed to build an odd-order polynomial model to maintain the phase relationship between the indices. The results of the regression analysis (Table 9) show that the multiple correlation between TRWI and IPR YR is quite strong ($R = 088$); the model adequately describes the relationship between the response and predictors, and the free term is statistically significant ($p < 0.05$).

Table 9. Regression summary for dependent variable TRWI (SITE 2)

N=26	Regression Summary for Dependent Variable: TRWI-2 (SITE 2.sta) $R = 0.88$; $R^2 = 0.78$; F (3.22) = 25.65; p <, 00000 ; Std.Error of estimate: 0.50253					
	b*	Std.Err. of b*	b	Std.Err. of b	t(22)	p-value
Intercept			0.048793	0.104385	0.46743	0.044788
IPR	1.71091	0.355526	1.644247	0.341675	4.81232	0.000083
IPR^3	-1.85763	0.867051	-0.806391	0.376384	-2.14247	0.043475
IP^{R5}	1.02733	0.612437	0.149594	0.089179	1.67745	0.107606

Source: developed by the authors

The adequacy of the model is confirmed by the F-test. It should be noted that the predictor IPR5 did not achieve statistical significance, as it did not satisfy the requirement $p < 0.05$. However, its removal from the model worsens the overall picture and adequacy of the model.

$$TRWI = 0.048 + 1.644 \cdot IPR\ YR - 0.806 \cdot \\ \cdot IPR^3\ YR + 0.149 \cdot IPR^5\ YR. \tag{5}$$

Model (5) adequately describes the variations in TRWI in the studied interval (Fig. 10a), with the model curve practically repeating the behaviour of the original series. Analysis of the residuals (Fig. 10b) showed that they are close to 'white noise', i.e. they prove that the studied model is adequate.

The adaptation of forests to global climate change is a matter of debate. There is uncertainty as to whether climate change will increase or decrease forest growth and productivity. In particular, B. Bouslimi *et al.* (2022) and E.A. Boakye *et al.* (2023) argues that high temperatures can cause both an increase and a decrease in wood density, mainly due to their effect on tracheid lignification and cell wall thickening. The width of the rings correlated positively and significantly with the average temperature and annual precipitation, while the density of the rings correlated negatively and significantly with the average temperature and annual precipitation.

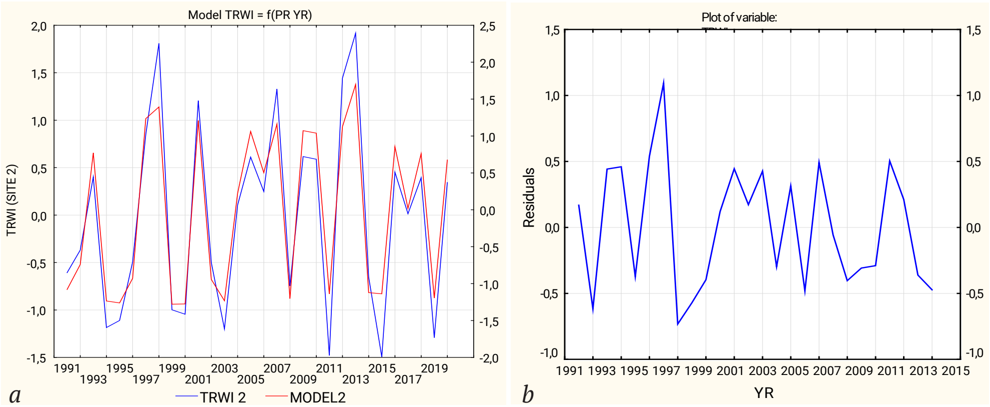


Figure 10. Polynomial model TRWI-IPR YR (SITE 2)

Note: a – TRW dynamics; b –TRW residual dynamics

Source: compiled by the authors

Given that the climate change scenario (IPCC 2022) is likely to be spatially heterogeneous on a regional scale, there is evidence that the response of *Quercus robur L.* to climatic conditions varies geographically, so determining the response of tree species to regional climate change is important for forest prediction and management. The problem with such studies, as noted by D. Perkins *et al*. (2018) and C. Leuschner *et al*. (2023), is that unfavourable climatic conditions are not the only cause of growth degradation, as there are other significant causes, such as soil fertility, groundwater, and competition among species. Therefore, identifying the climatic signal as a controlled predictor against a backdrop of a number of factors, both internal (species, origin, competitive status, age, size) and external (relief, slope, altitude, soil conditions, diversity of plantings, competition between plantings, mixing of species, etc.) is a major problem. It should be noted that the above factors are deterministic, their variability over time is insignificant and predictable, unlike climatic signals, which are stochastic in nature, especially precipitation patterns. The studies by D. Perkins *et al*. and C. Leuschner *et al*. use average annual climate indicators, which, although random, are too smoothed out as a result of averaging, primarily in relation to average annual temperatures. There is also uncertainty regarding annual precipitation totals associated with the cold period – solid precipitation. In current study, the use of climatic temperature signals such as average monthly maximum and minimum temperatures appeared to be much more sensitive seasonal predictors, especially in the spring-summer season.

The use of TRWI as a tree's response to external influences also contains uncertainty due to the construction of the index. Since evolutionary growth, in particular that of *Quercus robur L.*, is a non-stationary process in which a series of local extrema (Fig. 4a) are present against the backdrop of a global maximum (Fig. 3), the interpretation of useful information may depend on the algorithm used to construct the TRWI index. The contrasting seasonal precipitation patterns of Central Polissya did not manifest themselves in the growth responses of *Quercus robur L.*, which is able to withstand droughts thanks to its deep taproot system, which increases access to groundwater, unlike annual precipitation totals. This ensures the relatively high resistance of *Quercus robur L.* to prolonged dry spells in its natural range. The correlations between TRWI and average annual temperatures were, on the contrary, rather weak compared to the correlations at the seasonal level. At all study sites, a negative correlation was found between TRWI and maximum surface air temperature. As expected, the correlation with precipitation was positive, which is consistent with the results presented in studies by A.M. Petriţan *et al*. (2021), Ch. Sun *et al.* (2022), I.M. Koval & A. Bräuning (2024). Spatial-temporal variation in temperature and precipitation fields are the most important factors in regional climate change. Polynomial models constructed separately for temperature climate signals and precipitation appeared to be sufficiently simple and adequate, and their verification showed a decent match with the actual TRWI signal. With reliable climate forecast data, the models obtained can be used both to forecast TRWI and to look into the history of tree development with the relevant historical climate data for a given locality.

Climate warming may lead to a rapid decline in population growth, especially at the edge of the range, and, as a result, to a retreat in the distribution of species in central Ukraine. Therefore, the assessment of long-term growth trends at the edge of the range of *Quercus robur L.* deserves further attention. Significant progress has been made in understanding the factors affecting temperate forest zones. Despite this, researches by A. Gazol *et al.* (2018) and L. DeSoto *et al*. (2020) in this area has focused on the impact of both internal and external factors on the functional state of forests, adaptation methods and the overall carbon balance of forests. The issue of wood quality, against the backdrop of climate challenges, receives significantly less attention. G. Giroud *et al.* (2017) demonstrated that the overall density of wood and its modulus of elasticity increased with temperature and precipitation, regardless of species.

Wood density is a decisive factor in determining wood quality in temperate ecosystems. Climate variables play an important role in shaping wood density, creating challenges for forest managers and stakeholders in the wood processing industry in adapting to climate change. Understanding the impact of both climatic and non-climatic factors on wood density is essential for the development of a sustainable wood processing industry, while effectively minimising negative impacts and optimising economic aspects. Forest managers can use this knowledge to optimise timber production strategies, ensuring long-term environmental sustainability amid ever-changing climate challenges. Wood quality attributes related to wood characteristics are mainly determined by cambium activity (Zhang *et al*., 2020). Among the various attributes, wood density is crucial as it influences strength, durability and manufacturability.

Furthermore, wood density is closely related to its moisture content, which in turn influences its drying schedules. Thus, understanding the impact of climate change on wood density is also important for minimising any negative effects on wood quality, which is a key factor in the success of the woodworking industry.

Conclusions

The conducted study provides insight into the response of *Quercus robur L.* trees to changes in the current climate of the Polissya region of Ukraine. The results show that, given the predicted drier climate in temperate latitudes in the future, the condition of forest ecosystems will be more dependent on annual precipitation totals in both the current and previous years. The relatively high tolerance of oak trees to water shortages is confirmed by the fact that the *Quercus robur L.* trees studied did not show a significant decrease in growth in relatively dry years compared to the trend growth. The powerful root system of mature *Quercus robur L.* trees indicates their potential to cope with moisture deficits and allows them to withstand long periods of dry weather, as evidenced by their growth response. The response of young forests is another matter. Monthly precipitation totals show some stability during the winter season and a certain increase of up to 20% in the spring season; in summer and autumn, there is a noticeable decrease in precipitation, with the annual precipitation total showing a steady downward trend at a rate of about 1 $mm \cdot yr^{-1}$. Assessing the impact of temperature signals throughout the entire period of forest growth is challenging, as there is a steady trend towards higher maximum and minimum temperatures. The average ground-level air temperature has risen significantly since the 1980s at all study sites, by more than 2°C. Moreover, for all seasons, there has been a significant increase in the minimum temperature to 3°C, against a backdrop of relatively stable maximum temperatures, with the exception of the summer season. The climatic history of a forest is determined by its age. Thus, it is advisable to calculate climatic signals based on the age of the forest. Against the backdrop of climatic challenges, the biological development curve of *Quercus robur L.* trees is experiencing an extreme, so these influences may have different effects in the early and late stages of development. TRWI indices at all sites showed a noticeable correlation with seasonal climate signals, in particular with IPR SPR. For sites SITE2 and SITE4, the statistical relationship was strong (0.76-0.88). The transition from annual climate indicators to seasonal climate signals significantly strengthened the statistical relationship with TRWI, as it was possible to partially eliminate noise from the useful signal, which allowed for the construction of adequate statistical polynomial regressioSn models. There is an urgent need to study the response of young forests to climatic temperature challenges, which can be significantly affected even by minimal temperatures.

Acknowledgements

None.

Funding

None.

Conflict of Interest

None.

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Дендрохронологічна оцінка кліматичних ризиків для відтворення дубових лісів в Українському Поліссі

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Анотація. Погіршення кліматичних умов, спричинене глобальним потеплінням, становить загрозу для сталого розвитку лісових екосистем, зокрема дубових насаджень, які є важливою складовою лісового господарства України. Мета дослідження — визначити особливості реакції росту дерев дуба черешчатого (*Quercus robur* L.) на тривалі кліматичні зміни, що призводять до посушливості в умовах Українського Полісся. Проаналізовані градієнти помірного клімату в локаціях зростання дерев *Quercus robur* L. в Україні, а саме кліматичні фактори (екстремальні температури, опади), що впливають на ріст та розвиток дерев в часовому масштабі місяць та сезон. Отримані результати надають важливу інформацію, щодо регіональних перспектив вирощування дубових насаджень на території України. Випадкові кліматичні фактори, які діють синергетично з системними, негативно впливають на ріст дерев, незалежно від особливостей системи управління лісами. Досліджено вплив кліматичних умов на радіальний приріст дерев *Quercus robur* L. в межах його природного ареалу. Особливу увагу приділено ситуаціям, коли аналізовані дерева утворювали кільця ширина яких виходила за межі інтервалу – середнє плюс-мінус середнє квадратичне відхилення ($\bar{R} \pm SD$). Розроблені хронології кліматичних сигналів, що охоплюють новий референтний період 1991-2020 рр. для досліджуваних локацій. Розраховані прості індекси екстремальних середньомісячних температур повітря та індекси місячних сум опадів. Проведений кліматичний аналіз років, в які спостерігалися аномалії росту дерев *Quercus robur* L., що ідентифікувалися індексом ширини кільця TRWI. Встановлено, що статистично значимий вплив на радіальний приріст мають річні суми опадів та максимальні температури повітря у весняно-літній сезон. Побудовані поліноміальні моделі дозволяють передбачити зміни в динаміці росту дерев *Quercus robur* L., для досліджуваного регіону

Ключові слова: зміна клімату; кліматичні сигнали; дендрохронологічний аналіз; ширина кільця дерева; індекс ширини кільця

Received: 23.07.2025; Revised: 21.10.2025; Accepted: 27.11.2025

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 16(4)

UDC 581.9:574(65)
DOI: 10.31548/forest/4.2025.31

Diversity and floristic analysis of *Pistacia lentiscus* L. (Anacardiaceae) groups in Tiaret region (West Algeria)

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Suggested Citation:

Nouar, B., Berrabah, H., Maamar, B., Aouadj, S.A., & Nouar, M.A. (2025). (2025). Diversity and floristic analysis of *Pistacia lentiscus* L. (Anacardiaceae) groups in Tiaret region (West Algeria). *Ukrainian Journal of Forest and Wood Science*, 16(4), 31-56. doi: 10.31548/forest/4.2025.31.

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Abstract. This study aimed essentially at the knowledge and analysis of associated *Pistacia lentiscus* L. groups in the Tiaret region. By an analytical and statistical approach of the floristic inventories made in this area, three stations (Saffalou, Plateau and Guertoufa) were selected during the optimal vegetation seasons March-June between 2015-2018. A total of 166 species was identified; these species grouped into 131 genera and 43 families highly dominated by Angiosperms (98.2%). The most represented families were *Asteraceae*, *Poaceae*, *Fabaceae*, *Cistaceae*, *Lamiaceae* and *Brassicaceae* with percentages (15.1%, 10.8%, 9%, 6%, 5.4% and 4.8%), respectively. The biological spectrum of the flora was dominated by Therophytes (51.2%), whereas Mediterranean species group was well presented (54, 8%) compared to the other groups. Ecological indexes calculation showed that, Shannon index revealed a high diversity (H = 4.6), Pielou Equitability (J = 0.9) indicated a regularity in species distribution whereas Simpson index (1 - D = 0.98) reflected a low diversity of stands. Meanwhile, the overall perturbation index (PI = 63%) reflected the openness of the environment. Moreover, Jaccard (S) similarity coefficient remained less than 50% in all the compositions between the stations, reflecting a heterogeneity in the floristic composition of these stations. The Agglomerative Hierarchical Classification (AHC), revealed a division of species into two main groups 91.56% and 8.43%. Subsequently, Factorial Analysis of Correspondence (FAC) reflects an opening of the environments in the studied groups and installation of species with short life cycle that adapt to local arid conditions. The results obtained provide a diagnosis of the condition of the plant cover in the face of ecological factors, and can be used by foresters to improve the management, protection and restoration of these natural areas

Keywords: mastic trees; floristic richness; ecological factors; thyrophetisation; aridity

Introduction

The Mediterranean region represents one of the world's most valuable centres of biodiversity and considered as one of the richest hotspots of the world with over 24,000 species distributed in the large territory of the Mediterranean Basin, where the interaction of climatic, geographical, and anthropogenic factors gives rise to unique plant communities. This hotspot has a long history of modification of natural ecosystems by human activities, and it is one of the regions that will face extensive changes in climate (Vargas, 2020).

The authors B. Gordo & S. Hadjadj-Aoul (2019) explored the floristic endemism in the Algerian-Moroccan mountain range of the Ksour (Naâma, Algeria), providing a comprehensive study on plant species unique to this area. Their research highlighted the distribution and significance of these endemic species, which are crucial for understanding regional biodiversity and ecosystem stability. A.D. Solomou (2025) examined the Mediterranean Basin within the broader context of terrestrial biomes, focusing on the impact of global warming on ecological and biodiversity patterns. His work provided an essential synthesis of the biome's vulnerability to climate change, emphasising the importance of conservation measures in this biodiverse region. Researchers A. Benkhettou *et al.* (2022), reported that regions of climatic transition between humid and arid are particularly susceptible to degradation due to the combination of climate change and human activities which leads to increased habitat fragmentation and land degradation and abandonment. Due to its well-known rich taxonomy, its strong plant endemism and growing human threats, the entire Mediterranean Maghreb belongs to priority global concerns in terms of conservation biology of which the North of Algeria is home to a diversity of rare and endemic flora.

In the western part of Algeria in general, a significant degradation of forest and pre-forest ecosystems has been observed and particularly in the mountainous areas of Tiaret by multiple human activities of which repeated forest fires remain the most serious and threatening phenomenon (Safa *et al.*, 2022), leading to changes in the floristic composition and structure of plant assemblages. N. Zemmar *et al.* (2020) focused on the floristic diversity in Bissa Forest, located in Chlef, Algeria. The authors analyzed the plant species present in this southern Mediterranean ecosystem, revealing the richness and ecological significance of the area's vegetation for understanding Mediterranean biodiversity. A. Saidi & A. Keifa (2024) examined the vascular plant diversity in the Mimouna Forest in north-western Algeria. Their research contributed to the knowledge of plant diversity in this forest, emphasising the importance of preserving its floristic heritage in the face of environmental challenges.

The study of spontaneous populations of *Pistacia lentiscus* L., a characteristic Mediterranean species, which is distributed in a wide range of habitats (forests, brush and scrubland) in both the Tell region and in forested areas with a very interesting richness of a wide range of bioactive compounds and multiple virtues for use in human medicine (Atmani *et al.*, 2025). W. Benchiha *et al.* (2024) investigated the antioxidant activity and the content of phenols and flavonoids in aqueous extracts from the leaves of *Pistacia lentiscus* L. Their study highlighted the potential of this plant as a source of natural antioxidants, with implications for both pharmacological and environmental applications. A. Bouchfara *et al.* (2025) evaluated the antibacterial and antioxidant properties of essential oils from *Pistacia lentiscus*, focusing on the impact of total phenolic content on antioxidant efficacy. Their findings provided insights into the potential medicinal applications of *Pistacia lentiscus* essential oils. The research by S. Moussaoui *et al.* (2025) evaluated the polyphenolic profile and various bioactivities (antioxidant, anti-cholinesterase, and anti-alpha-amylase) of *Pistacia lentiscus* L. leaves. The study highlighted the broad therapeutic potential of this plant, particularly in relation to metabolic and neurodegenerative diseases

Also, the plant plays a key role in the stabilisation of local biocoenoses, provides a deeper understanding of the mechanisms underpinning the conservation of plant diversity under ecological stress and climatic variability. Such analysis is essential for assessing the ecological potential of these formations and for developing strategies aimed at the restoration of natural ecosystems. M.N. Youcefi *et al.* (2020), confirm that one of the primary goals in community ecology is to determine the relative importance of processes and mechanisms that control biodiversity.

The insufficiency of the studies of these plant groups in Tiaret mountains, prompted to select this species, that grows spontaneously in this region and occupies an important area as a research model on this subject in order to inventory and identify their associated species and to determine the ecological factors that influence these plant groups through ecological indexes.

This study's aim was to investigate the ecological characteristics of *P. lentiscus* L. populations in the Tiaret region in order to assess their adaptive potential and environmental significance towards.

Materials and Methods

The study area was an integral part of the Tiaret Mountains, located in the north of the department (wilaya) and embracing in south the city of Tiaret, they are between 700 and over 1,200 m high (Fig. 1). The dominant bioclimate was of the type semi-arid in its cool winter variant mesomediterranean level (Miara *et al.*, 2020). Soil textures vary between silty-sandy, silty-clay-sandy and silty (Nouar *et al.*, 2020).

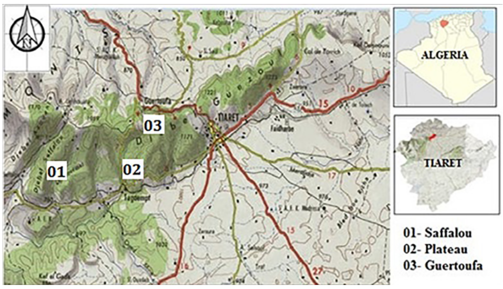

Figure 1. Geographical location of study stations

Source: developed by the authors

In order to obtain the maximum information on the studied groups and to cover the maximum of area by floristic surveys, it was preselected three (03) stations in the natural range of *P. lentiscus* L: Saffalou, Plateau and Guertoufa. A stratified sampling was conducted in three selected areas, which were relatively homogeneous, following the methodology outlined by M. Gounot (1969).

I. Benmehdi *et al.* (2013), have highlighted that a surface of 100m^2 seems to be sufficient for these mastic tress groups. Therefore, it was conducted 10 floristic surveys per station, 30 in total during the optimum period of vegetation (March to June) in the years 2015 to 2018 using the minimum area survey method adopted by J. Braun-Blanquet (1951) lists of all species present in the floristic cortege of the target species. Each species was accompanied by two indexes: abundance-dominance and sociability. Field material was as follow: a rope to determine surface area; a GPS to locate each survey and a station description was carried out citing altitude, soil characteristics and physiognomic recovery rate estimation.

The identification of taxa was made using the flora of P. Quézel & S. Santa (1962-1963) updated by the index of A. Dobignard & C. Chatelain (2010-2013). The different biological types were performed using the method of Raunkiaer. Collected specimens were pressed and dried and vouchered. Species identification was performed by local botanists. Then, they were conserved in the laboratory of Botany at the Faculty of Sciences of Nature and Life, Earth Sciences and Universe, University of Tlemcen (Algeria). In accordance with the Executive Decree No. 12-03 (2012), fixing the list of the non-cultivated protected plants throughout Algeria and by extension subject to the objectives and obligations of the Convention on Biological Diversity (1992).

The Table 1 of flora inventories by species was used as a database for systematic (families, biological and biogeographical types) and statistical analysis for ecological indexes (Table 2), Agglomerative Hierarchical Clustering (AHC) species and Factorial correspondence analysis (FAC). The restitution of the graphs was carried out by Microsoft Excel software and Minitab 18.1 software for statistical processing. AHC was used to determine the groups of species, allowing to individualize the groups of species and within each group, it was considered the floristic indicator as a guiding factor in the diagnosis of vegetation dynamics (Benmehdi, 2012). FAC was performed to show the ecological gradients that influence the vegetation studied. S. Ghezlaoui & N. Benabadji (2018), H. Khennouf *et al.* (2018) and M. Souddi & B.D. Ghezlaoui-Bendi-Djellou (2020) considered this method to be the most appropriate techniques for the discrimination of plant groups and the determination of ecological gradients.

Table 1. Phytosociological table of inventoried species

Taxa	**Saffalou**										**Plateau**										**Guertoufa**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Allium subvillosum Salzm. ex Schult. & Schult. f																	1.1	1.1							1.1	2.1	1.1	2.1	1.1	
Narcissus serotinus L.												1.1		2.1	1.1	+									+					
Pistacia lentiscus L.	2.2	2.3	1.1	1.2	2.3	1.2	2.3	1.1	1.1	2.3	1.1	1.1	1.1	2.1	1.1	2.1	+	+	1.1	1.1	2.3	2.1	3.3	3.3	2.1	2.1	2.1	2.3	2.1	2.1
Pistacia terebinthus L																	1.1			1.1										
Ammoides pusilla (Brot.) Breistr								1.1																						
Ferula communis L.								1.1																						
Ferula lutea (Poiret) Maire					2.2			1.2								+					+				2.1			+		
Nerium oleander L.																													+	
Chamaerops humilis L			2.2			1.2		2.3	2.2													+		+				+		
Asparagus acutifolius L.				2.2	1.2		1.1	1.1		1.1		+	1.1	1.1			1.1	1.1	1.1		+	1.1		1.1		1.1		1.1	1.1	
Asparagus albus L.								1.2																						
Dipcadi serotinum (L.) Medik															+	+											+			
Drimia maritima (L.) Stearn			1.1				1.1		1.1	1.1	+											1.1								
Muscari comosum L. Mill											+					+		+									1.1	1.1		
Ornithogalum baeticum Boiss.						1.1	2.1			2.1			+			1.1								+			+			
Anacyclus clavatus (Desf.) Pers						1.1		2.1								+	1.1	1.1		1.1			1.1		+	1.1		+		
Atractylis cancellata L.																													2.1	
Bellis annua L. *subsp. annua*													1.1		1.1				1.1											
Bellis sylvestris L.												2.1				1.1					1.1									
Bombycilaena discolor (Pers.) M.								+								+			2.1				+							1.1
Calendula arvensis (Vaill.) L.	+		2.1			1.1			2.1						+															

Table 1, Continued

Taxa	Saffalou										Plateau										Guertoufa									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Carduus pycnocephalus L. subsp. *pycnocephalus* L (M).																							+				1.1		1.1	
Cirsium echinatum (Desf.) DC.																							+							
Crepis vesicaria L			+						+				+												1.1		1.1			
Echinops spinosus. subsp eu.spinosus Greuter								1.2											1.1											
Glebionis segetum (L.) Fourr																1.1	2.1	3.1		+		1.1				1.1	1.1			
Glossopappus macrotus (Durieu) Briq. & Cavill		+									2.1		1.1															1.1		
Hedypnois rhagadioloides (L.) F. W. Schmidt												+		+	+								1.1							
Helichrysum stoechas (L.) Moench					1.2																1.1									
Helminthotheca glomerata (Pomel) Greuter														+										1.1					+	
Hyoseris radiata L.						1.1		2.1																						
Hyoseris scabra L.						+																								
Hypochaeris radicata L.												+																		
Leontodon tuberosus L., Hem											+																			
Micropus supinus L																						1.1								+
Pallenis spinosa (L.) Cass. subsp. *spinosa*								2.1																				+		
Senecio giganteus Desf	+	1.1			+	1.1					+	1.1	1.1								1.1	1.1			1.1					
Sonchus tenerrimus L. *subsp. tenerrimus*																								1.1						
Taraxacum obovatum (Willd.) DC.																								1.1		2.1				

Table 1, Continued

Taxa	Saffalou										Plateau										Guertoufa									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Tolpis barbata (L.) Gaertn.																								+	+	+				1.1
Borago officinalis L																									+					
Cynoglossum cheirifolium L														+																
Echium plalltagineum L.								+																						
Neatostema apulum (L.) I.M.Johnst																			1.1											
Alyssum alpestre L.																										+				
Alyssum simplex Rudolphi			+						+													+								
Biscutella didyma L.						+						1.1			2.1	1.1		2.1		2.1										+
Capsella bursa–pastoris (L.) Medik.	+																													
Eruca vesicaria L											1.1						+	+			+								+	
Lobularia maritima (L.) Desv .	1.2	1.1			1.2	2.2	1.1			1.1	2.2	2.1	2.1				+	1.1			3.3	2.1	2.1	1.1	+	+	1.1	2.1		+
Matthiola lunata DC.											2.3	1.1	+	1.1	+						1.1							2.1		
Sinapis arvensis L	1.1		1.1			2.1	1.1		1.1	1.1						+							1.1						1.1	
Lomelosia stellata L								2.1																		+				+
Lonicera implexa Aiton												1.1		1.1					1.1				1.1						+	
Paronychia argentea Lam.						+					1.2			1.1			1.2	1.2	2.2			1.2	1.2		+		1.1			
Silene colorata Poir. subsp. *colorata*															+															
Silene latifolia Poir. *subsp. Latifolia*															+															
Silene muscipula L.																													+	
Silene secundiflora Otth.																										+				
Cistus creticus subsp. eriocephalus (Viv.) Greuter & Burdet					2.2	1.2		1.2					2.1		2.2				1.1		1.1			1.1	2.1	2.1	2.1	1.1	1.1	

Table 1, Continued

Taxa	Saffalou										Plateau										Guertoufa									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Cistus halimifolius L		1.2		2.2	2.2						2.2	2.2	1.2	1.2											2.1		3.3	3.3		
Cistus ladanifer subsp. mauritianus Pau & Sennen	2.2	2.2			2.2																					1.1				
Cistus salvifolius L.	1.2	2.2	1.2	2.2			1.2	1.2	1.2	1.2	1.2	1.2	2.1	2.2	1.2	1.1		2.1	1.1			1.2	1.1	1.1	2.1	1.1	1.1	1.1	1.1	1.1
Fumana thymifolia (L.) . Verlot																+														
Helianthemum cinereum subsp. rotundifolium (Dunal) Greuter & Burdet			+						+																					
Helianthemum hirtum subsp. ruficonum (Viv.) Maire											+																			
Helianthemum pilosum L.							2.1	+		2.1																				
Helianthemum salicifolium (L.) Mill			2.1						2.1																					
Tuberaria guttata subsp. variabilis (Willk.) Litard		1.1	1.1			2.1			1.1													2.1								
Convolvulus cantabrica L.								2.1																						
Convolvulus siculus L. *subsp. siculus*			+						+																					
Sedum sediforme (Jacq.) Pau								1.2								2.2										1.2		+	1.2	
Juniperus oxycedrus L.		+									2.1	1.1	2.3	3.3	3.3	2.3		2.1	2.3	1.1	3.3	3.3		2.1	2.1	3.3	2.3	1.1	2.3	3.3
Tetraclinis articulata (Vahl) Mast																												+		+
Arbutus unedo L.	2.3	2.1			2.3							+	1.1	1.1									1.1		+	1.1	1.1	1.1	+	
Euphorbia falcata L																				+										
Astragalus edulis Bung																			2.1											
Bituminaria bituminosa (L.) C.H.Stirt																													1.2	

Table 1, Continued

Taxa	Saffalou										Plateau										Guertoufa									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Calicotome spinosa (L.) Link subsp. *spinosa*			1.2	2.2	2.2	1.2		2.1	1.2		+	1.1			1.1	+			1.1		2.1		2.1		1.1		1.1	1.1	2.1	2.1
Coronilla scorpioides (L.) W.D.J. Koch			+						+																					
Genista tricuspidata Desf. *subsp. tricuspidata*			2.2			1.2		2.2	2.2																					
Hedysarum pallidum Desf.							1.2	+		1.2																		1.1	1.1	
Lotus creticus subsp. cytisoides (L.) Arcang				1.2	1.2									1.1									+		1.1					
Lotus subbiflorus Lag						1.2																2.1								
Medicago italica (Mill.) Fiori														+	1.1															
Medicago orbicularis (L.) Bartal																+							1.1							
*Ornithopus compressus*L.												1.1				1.1														
Scorpiurus muricatus. subsp sulcatus (L.) TheIl.						+	+			+					+							1.1								
*Trifolium arvense*L.																										1.1	1.1			
Trifolium cherleri L.																			+					+						
Trifolium stellatum L.															+				+				1.1	2.1			1.1			
Quercus coccifera L. *subsp coccifera*	1.2	1.2				1.1	1.2			1.2																			+	
Quercus ilex subsp. ballota (Desf.) Samp		1.1	1.1	1.1	1.1			1.1	1.1		2.3	3.3		1.1	1.1	2.3	1.1	2.1	1.1	2.1	1.1	1.1	2.1	+	2.3	1.1		2.3	1.1	1.1
Quercus suber L.		+		1.1	1.1																									
Erodium chium (L.) Willd.			+						+																					

Table 1, Continued

Taxa	Saffalou										Plateau										Guertoufa									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Erodium cicutarium L'Her.																		+				+								
*Erodium malachoides(*L.*) L'Her*											+							+										3.1		
Erodium moschatum (Burm.) L'Her.	2.1	1.1	2.1	+		+	1.1		2.1	1.1	1.1	1.1		1.1							1.1	1.1	1.1	1.1			+	3.1	1.1	+
Geranium molle L.	+																					+								
Geranium purpureum Vill													1.2																	
Iris planifolia (Mill.) T. Durand & Schinz										+																				
Moraea sisyrinchium (L.) *Ker Gawl*																				+										
Romulea bulbocodium (L.) Seb.et Maur.																					+									
Cleonia lusitanica L.								1.1																						
Lavandula stoechas L.	2.2	2.2		1.2	1.2	1.2	2.2			2.2	1.1		2.1	1.1	2.1	1.1			1.1		1.1	2.1	1.1	1.1	2.1	1.1	1.1	2.1		2.1
Marrubium vulgare L.																						1.2								
Rosmarinus officinalis L.							3.3			3.3														2.3	2.1	2.1				
Salvia verbenaca (L.) Briq.																						1.1								
Stachys ocymastrum (L.) Briq.								1.1																						
Teucrium pseudochamaepitys L.												1.1			1.1	1.1	1.1		1.1				+		1.1	2.1	2.1			+
Teucrium thymoides Pomel,			1.2				1.2	1.2	1.2	1.2					+									1.1						
Thymus ciliatus (Desf.) Benth. subsp. *ciliatus*			1.2		1.2	2.3	2.2		1.2	2.2		1.2			1.2	1.2			1.2			2.2				1.2		1.2		1.2
Fritillaria oranensis Pomel							+			+																				
Gagea algeriensis Chabert																						+								
Jasminum fruticans L													1.1	1.1	1.1	2.1	+	1.1	+	1.1			1.1	1.1		2.1	1.1			

Table 1, Continued

Taxa	Saffalou										Plateau										Guertoufa									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Olea europea L. *subsp. europaea*		+	2.1						2.1																				+	+
Phillyrea angustifolia L.	2.3	2.3	1.1	3.3	2.3	3.3	2.3		1.1	2.3	2.1	3.3	3.1	2.1	2.1	2.1	3.3	2.3	2.3	2.3	1.1	2.1	2.3	2.3	2.3	2.1	2.3		2.3	
Ophrys fusca Link.																										+				
Ophrys speculum Link							1.2			1.2																				
Ophrys tenthredinifera Willd. p.p.					+		+			+																				
Orchis olbiensis Reut. ex Gren.				+																										
Orobanche gracilis Sm									+																					
Parentucellia latifolia (L.) Caruel						1.1																								
Phelipanche ramosa (L.) Pomel															+															
Papaver argemone L												+																		
Papaver hybridum L.																	+						2.1						1.1	
Papaver pinnatifidum Moris.														+																
Pinus halepensis Mill.	+												1.1	1.1										+						
Globularia alypum. Subsp alypum							1.2			1.2																				
Misopates orontium (L.) Raf.																												+		
Plantago afra L																												+		
Plantago albicans L.												2.1		2.1															1.2	
Plantago lagopus L.	1.1					2.3	1.2			1.2				2.1				1.1	2.1	2.1			+			1.1			2.1	
Aegilops geniculata Roth								2.3															1.1							

Table 1, Continued

Taxa	Saffalou										Plateau										Guertoufa									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Ampelodesmos mauritanicus (Poir.) Durand & Schinz	1.2	1.2	2.2		1.2	2.2	3.2	3.3	2.2	3.2	1.1		1.1	1.1	2.3	2.1			2.1		1.1	1.1	1.1		+	1.1			2.2	1.1
Anisantha rubens (L.) Nevski						1.2							+		1.1															
Avena barbata Pott ex Link												+					1.1		1.1						+	+		2.1	1.1	
Briza maxima L.							1.2	1.1		1.2																				
Bromus lanceolatus Roth.												1.1																		
Bromus madritensis L															1.1		2.1		2.1				2.1		2.1		2.1	2.1	2.1	3.1
Patzkea coerulescens (Desf.) H. Scholz						+																								
Cynosurus echinatus L																				2.1			2.1			2.1	+			
Echinaria capitata (L.) Desf.							1.1			1.1														1.1		1.1				
Hordeum murinum subsp. leporinum (Link) Arcang												1.1					2.1			2.3			1.1						2.1	
Lagurus ovatus L.								2.1									1.1	1.1		1.1										
Macrochloa tenacissima (L.) Kunth							3.2			3.2																		1.2	1.2	
Melica ciliata L.														1.1			1.1													
Phalaris canariensis L																			1.1											
Phleum pratense subsp. *bertolonii* (DC.) Bornm													1.1																	
Poa bulbosa L. *subsp. bulbosa*												1.1		1.1									1.1	+		2.1	2.1			
Stipa capensis Thunb												1.1														1.1				

Table 1, Continued

Taxa	Saffalou										Plateau										Guertoufa									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Rumex bucephalophorus L.						1.1	+			+	3.3	2.1	+	2.1	2.1		2.3	2.3		2.1	2.2	3.3	1.1		2.1		2.1	2.3		2.1
Lysimachia arvensis (L.) U. Manns & Anderb	+		2.2	1.1	+	2.1			2.2		+	+	+	+	1.1	1.1			+		+	1.1	1.1	1.1	+		+			
Lysimachia monelli (L.) U. Manns & Anderb																													+	
Cytinus hypocistis subsp. macranthus Wettst																											1.1			
Clematis flammula L																						1.1								
Ranunculus arvensis L.							+			+	1.1													+						
Reseda alba L. subsp. *alba*																						+								
Rhamnus lycioides. subsp. oleoides L.											1.1					1.1		1.1	1.1						+		1.1	1.1		
Sanguisorba minor subsp. *balearica* (Nyman) Muñoz Garm. & C. Navarro																													+	
Scrophularia canina L														+																
Smilax aspera L																						1.1								
*Tamarix gallica*L												+		+																
Thymelaea hirsuta Endl.				1.2		2.2		2.2						1.1								2.1	2.1						1.1	
Valerianella discoidea (L.) Loisel							1.1			1.1													+			+				
Asphodelus microcarpus Salzm et Viv.			2.1	2.1		1.1	2.1	1.1	2.1	2.1						1.1														

Source: developed by the authors

Table 1 of floristic records shows that *P. lentiscus* L. is often accompanied by shrubs and some very common herbaceous plants such as *Phillyrea angustifolia* L, *Cistus salvifolius* L., and *Quercus ilex subsp. ballota* (Desf.) Samp with frequencies over 80%. Other high frequency species which range between 60 to 80% include: *Lavandula stoechas* L., *Lobularia maritima* (L.) Desv., *Ampelodesmos mauritanicus* (Poir.) Durand & Schinz, *Juniperus oxycedrus* L., *Lysimachia arvensis* (L.) U. Manns & Anderb and *Calicotome spinosa* (L.) Link *subsp. Spinosa*. Both categories of these species are classified as faithful to *P. lentiscus* L. according to the definition established by I. Benmehdi *et al.* (2013). Species such as *Asparagus acutifolius* L., *Thymus ciliatus* (Desf.) Benth. *subsp. ciliatus*, *Cistus creticus subsp. eriocephalus* (Viv.) Greuter & Burdet, *Arbutus unedo* L. and *Jasminum fruticans* L. are medium frequency species, occurring between 40 and 60%, while the remaining species have frequencies of less than 40%.

The different index of floristic richness, Shannon-Wiener, Equitability of Pielou, Simpson and perturbation index were calculated for each station, while Jaccard index was used to compare between these three stations are presented in Table 2

Table 2. Formulas and objectives of the various ecological indexes used

Index	Formula
Shannon-Wiener	$H' = -\Sigma\ ni/N \log2\ (ni/N)$ ni – the effective of species i, N – the total number of species
Equitability of Pielou	$Eq = H'/\log2N$
Index of Simpson	$D' = (ni/N)/2$
The overall perturbation index (PI) Loisel & Gamila	PI = (Number of Chamaephytes + Number of Theophytes/ Total number of species) x 100
Jaccard index	S = (C/A + B – C) x 100, where A – all species of Group A, B – all species in Group B, C – the species common to both groups in comparison.

Source: developed by the authors

In order to better understand the different relations between the three studied sites it was performed the Shannon-Wiener index to assess the richness and relative abundance of species, followed by Equitability of Pielou to expresses the relationship between observed diversity and maximum diversity and accounts for species distribution in the sample. Simpson index was used measure the probability that two randomly selected individuals from an infinite population would belong to the same species. Then, the overall perturbation index (PI) to quantifies the thyrophetisation and finally, Jaccard index to reflect the similarity between plant groups.

Results and Discussion

166 taxa were inventoried from 30 floristic surveys, belonging to 131 genera and 43 botanical families in all stations. The distribution of these species in the large taxonomic groups indicates that Angiosperms largely dominate the flora (98.2%), specifically Dicotyledon (75.3%) followed by Monocotyledon (22.9%), whereas Gymnosperms only constitute (1.8%) (Table. 3).

Table 3. Distribution of taxa by taxonomic groups

Taxonomic groups	Saffalou				Plateau				Guertoufa				Study area			
	F	G	S	%	F	G	S	%	F	G	S	%	F	G	S	%
Gymnosperms	2	2	2	2.3	2	2	2	2.2	2	3	3	2.8	2	3	3	1.8
Monocotyledon	7	17	19	22.1	5	21	22	23.7	8	23	23	21.3	9	34	38	22.9
Dicotyledon	23	53	65	75.6	26	56	69	74.2	27	67	82	75.9	32	94	125	75.3
Total	**32**	**72**	**86**	**100**	**33**	**79**	**93**	**100**	**37**	**93**	**108**	**100**	**43**	**131**	**166**	**100**

Note: F – family, G – genera, S – species
Source: developed by the authors

It was noticed that the specific richness is irregularly distributed, the third station (Guertoufa) contains 108 species representing the maximum compared to the minimum of 86 species in the first station (Saffalou). Moreover, six richest families in terms of species, contain more than 50% of the total flora (Fig. 2). With *Asteraceae* (25 species; 15.1%), *Poaceae* (18 species; 10.8%), *Fabaceae* (15 species; 9%), *Cistaceae* (10 species; 6%), *Lamiaceae* (9 species; 5.4%) and *Brassicaceae* (8 species; 4.8%).

Species distribution in biological types for the total flora shows the dominance of Therophytes with (85 species; 51.2%), followed by the Hemicryptophytes (23 species; 13.9%), then the Chamæphytes (20 species; 12%) and in last position the Geophytes and Phanerophytes with the same percentage (11.4 %) each one. The total flora and of each study station by biological type is presented in Figure 3.

The analysis of the chorological spectrum of species shows the domination of the elements of the Mediterranean group on all other groups with (91 species; 54.8%) followed by the West Mediterranean (18 species; 10.8%), then the European-Mediterranean (9 species; 5.4%) for the entire study area and study stations (Fig. 4). The rest represents a low participation (less than 5%).

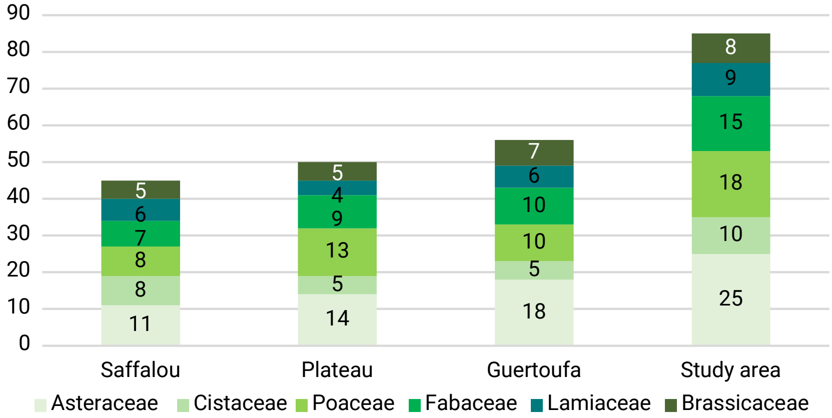

Figure 2. Species number of six dominant families in area and study stations
Source: developed by the authors

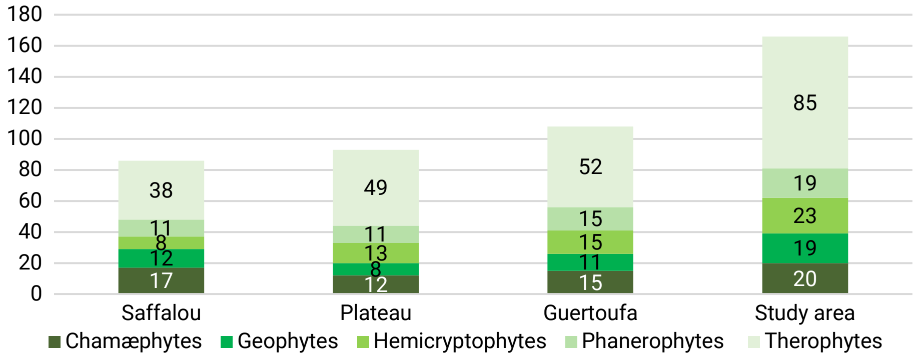

Figure 3. Species number of area and study stations by biological types
Source: developed by the authors

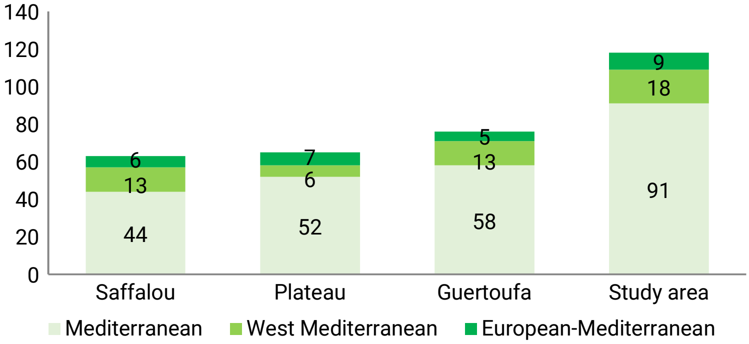

Figure 4. Species number of three dominant biogeographical types in area and study stations
Source: developed by the authors

The specific richness (S), the Shannon diversity (H), the Piélou equitability index (J), the Simpson index (1-D) and the Perturbation index (PI) of each station as well of the entire study area (Table 4) were calculated.

Table 4 presents the ecological indices for the three study stations and the overall area. The Shannon index (H), which measures species diversity, ranges from 4.2 to 4.37 at individual stations, reaching a value of 4.6 for the entire study area, indicating high biodiversity and healthy ecosystems that support a wide range of species. The Pielou equitability index (J) remains high at approximately 0.94 across all stations, suggesting a balanced distribution of species. However, for the overall area, this value decreases to 0.9, potentially indicating some unevenness in species distribution. The Simpson index (1-D), which measures the probability that two randomly selected individuals will belong to the same species, shows a low degree of species dominance (ranging from 0.98 to 0.9854), confirming the floristic diversity of the ecosystems. The perturbation index (PI), which assesses the level of ecological disturbance, varies from 62% at the Guertoufa station to 65.6% at the Plateau station. This suggests a moderate impact of anthropogenic factors, such as grazing and other ecological disturbances, which create conditions conducive to species with short life cycles.

Table 4. Comparison of indices of biological diversity

	Saffalou	Plateau	Guertoufa	Study area
Taxa S	86	93	108	166
Shannon H	4.202	4.246	4.372	4.602
Equitability J	0.9433	0.9368	0.9338	0.9001
Simpson 1-D	0.9816	0.9819	0.9837	0.9854
Perturbation PI	64%	65.6%	62%	63.3%

Source: developed by the authors

It is well documented that Jaccard similarity index is used for comparison between two sites by evaluating the resemblance, the more it exceeds fifty percent the more the sites are similar. Table 5 show this index performed between the different sites.

Table 5. Comparison of similarity coefficients between study stations

Jaccard (S)	Saffalou- Plateau	Saffalou- Guertoufa	Plateau- Guertoufa
	29%	37%	45%

Source: developed by the authors

Table 5 presents the results of the Jaccard similarity index (S) between the three study stations: Plateau, Guertoufa, and Saffalou. The Jaccard Index is used to measure the similarity between two sets, in this case, the floristic compositions of each station, where higher values indicate greater similarity. The results indicate a 45% similarity between the Plateau and Guertoufa stations, which suggests a moderate level of floristic overlap. This relatively higher similarity could imply that these two stations share several species and may have comparable ecological conditions or disturbances that allow similar species to thrive. The similarity between Saffalou and Guertoufa is slightly lower at 37%, indicating that while there is still a considerable overlap in species, the floristic composition of Saffalou and Guertoufa is less similar compared to the Plateau-Guertoufa pair. This difference could be attributed to variations in microclimates, soil types, or other ecological factors influencing species distribution. The lowest similarity is observed between Saffalou and Plateau, with a 29% similarity. This significant difference in floristic composition suggests that these two stations are ecologically more distinct, with fewer species in common. The variation in plant communities between these two stations may be influenced by differences in altitude, climate, or other environmental factors, leading to a greater divergence in species composition.

The determination of species groups through descending hierarchical classification are presented in (Table. 6; Fig. 5). According to the dendrogram of the AHC of the 166 species in the study area, it was distinguished two groups which are well individualized.

Table 6. Comparison of similarity coefficients between study stations

	Species number	%
Group 1	152	91.56
Group 2	14	8.43

Source: developed by the authors

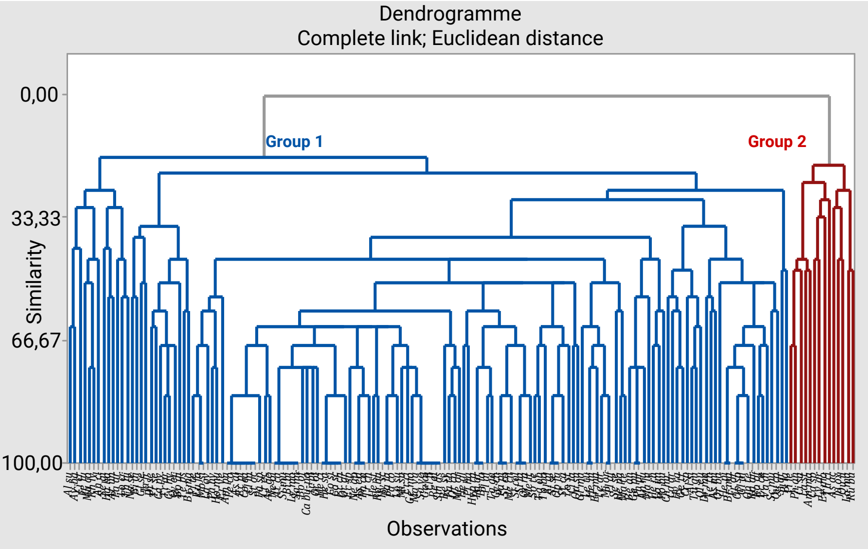

Figure 5. Dendrogram of groups species in the study area

Source: developed by the authors

Table 6 presents the results of a hierarchical classification of species observations in the study area, dividing the species into two distinct groups. The first group comprises 91.56% of the species (152 species), while the second group contains only 8.43% (14 species). This clear division highlights the dominance of a large number of species in the study area, with a smaller subset representing a less frequent or secondary group of species. Such a classification suggests that the plant communities in the region are structured in a way that a majority of species belong to one primary ecological group, while a smaller group of species might be more specialized or occur under specific environmental conditions.

Figure 5, which is a dendrogram of the species groups, visually represents this hierarchical classification. It helps to further illustrate the relationship and clustering of species, showing how closely related or distinct the different species are based on their ecological observations. The analysis reveals that the flora of the study area is dominated by a majority of common species, while a minority of species make up a secondary cluster, potentially indicating different ecological niches or environmental conditions. This finding underscores the variability and complexity of the region's plant communities.

The inertia rates of the first three axes are respectively 28.8%, 8.5% and 5.8% (Table. 7).

Table 7. Eigenvalues and percentage of inertia for the first three axes of the FAC

Variable	Factor 1	Factor 2	Factor 3	Communality
Variance	8.632	2.5647	1.7457	12.9425
% variance	0.288	0.085	0.058	0.431

Source: developed by the authors

The first axis summarizes the maximum information with an inertia rate of 28.8%, therefore the interpretation has been carried on the first factorial axis because the inertia rates of the other axes (02 and 03) are lower than 10% and the clouds are therefore very poorly structured in the factorial plane. The species having a strong contribution relative to the eigenvalues of this axis are mentioned in (Table. 8; Fig. 6).

Table 8. High contribution taxa for axis 1 of the FAC

Positive side of axis 01	Negative side of axis 01
Pistacia lentiscus 4.3023	*Stachys ocymastrum* -0.7325
Phillyrea angustifolia 3.8834	*Cleonia lusitanica* -0.7325
Cistus salvifolius 3.3987	*Convolvulus cantabrica* -0.7325
Quercus ilex 3.3201	*Echium plalltagineum* -0.7325
Lavandula stoechas 3.2365	*Asparagus albus* -0.7325
Ampelodesmos mauritanicus 2.9167	*Ferula communis* -0.7325
Lobularia maritima 2.8202	*Ammoides pusilla* -0.7325
Lysimachia arvensis 2.6625	*Sanguisorba minor* -0.6706
Juniperus oxycedrus 2.6009	*Lysimachia monelli* -0.6706
Erodium moschatum 2.4924	*Bituminaria bituminosa* -0.6706
Rumex bucephalophorus 2.3063	*Silene muscipula* -0.6706
Calicotome spinosa 2.3030	*Atractylis cancellata* -0.6706
Asparagus acutifolius 2.00301	*Nerium oleander* -0.6706

Source: developed by the authors

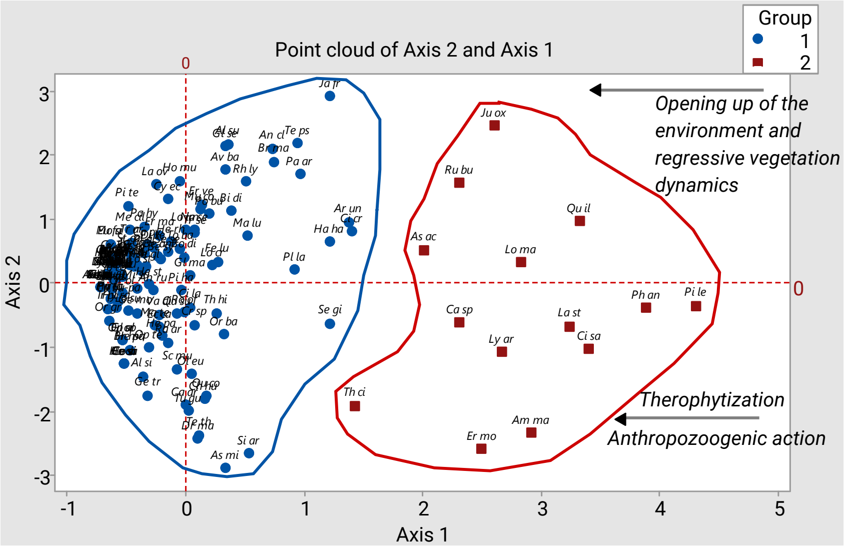

Figure 6. Factorial plan of the species in the study area (Axis1-2)

Source: developed by the authors

The floristic indicator of species around this axis (positive and negative side) is considered as a guiding factor in the diagnosis of vegetation dynamics. For this, the distribution of species helps to determine the ecological factors influencing the vegetation studied. The majority of group 1 species settle around the intersection of the two axes (close to zero) in the negative side of axe 1 with a low relative contribution to the values specific to this axis. The rest of the species of group 1 and the totality of the group 2 species are individualized in the positive side of axis 1 with an average and strong relative contribution to the values specific to this axis.

In terms of specific richness, it was found that the study area (03 stations) is very rich in species (166 taxa). Whereas in Tlemcen for instance in Western Algeria recorded by I. Benmehdi *et al.* (2013), for a sampling effort five times larger (150 surveys), there was a smaller richness (109 taxa). The dominance of families of *Asteraceae*, *Poaceae*, *Fabaceae*, *Cistaceae*, *Lamiaceae* and *Brassicaceae* go in the same direction with those of M.D. Miara *et al*. (2018), B. Nouar *et al.* (2020), in which these families dominate the vegetation cover of the Western Tellien Atlas of Tiaret. Biologically, the flora studied is composed of more than half of Therophytes with (51.2%), according to M. Barbero *et al*. (1990), thyrophetisation is considered as the ultimate stage of degradation of the different ecosystems with the dominance of sub-nitratophilic species linked to overgrazing.

The dominance of the Mediterranean biogeographic type is a well-established characteristic of the Algerian flora, a phenomenon that was first highlighted by P. Quézel (2002) for all North African countries. This dominance has been further supported by several studies in various regions and biotopes of Algeria. Notably, N. Yahi *et al.* (2008) and A. Boughani *et al.* (2009) demonstrated the prevalence of Mediterranean species in different Algerian ecosystems. Similar findings were reported by B. Guit & B. Nedjimi (2019), who studied Mediterranean flora in the steppes and the Saharan Atlas, and more recently by B. Taibaoui *et al.* (2020) and R. Larbi *et al.* (2021), who conducted research in forests and other biotopes across Algeria. These studies consistently show that Mediterranean species play a dominant role in shaping the floristic composition of Algeria, confirming the widespread distribution and ecological significance of Mediterranean plant types in the country.

Based on the results obtained, the Shannon index (S) is 4.6 for the study area (4.2, 4.24 and 4.37) for Saffalou, Plateau and Guertoufa respectively, according to I. Yabi *et al*. (2013), this means a high diversity within the plant group, indicating that the site conditions are very favourable to the installation of a large number of species in almost equal proportions. However, Pielou equitability (J) is 0.9 for the study area (0.94) for Saffalou, Plateau and Guertoufa with the same value (0.93), these values indicate a regularity in species distribution, thus inducing a relatively uniform spatial structure (Hachemi, 2015), while the Simpson index (1-D) is 0.98 for the entire study area and for the three sites, this reflects a low diversity of stands.

The perturbation index (PI) is in the order of 63.3% for the whole study area, it varies from a minimum of 62% (Guertoufa) to a maximum of 65.6% (Plateau). N. Hachemi (2015) signals that the importance of this index is proportional to the dominance of chamaephytes and especially of the therophytes who find their environment favourable to their development (sandy substrate, organic matter poverty); this also reflects a more open environment (Nouar *et al.*, 2020). The Jaccard index (S) values shows that the similarity between Plateau-Guertoufa stations is 45% and between Saffalou-Guertoufa is 37%, while the lowest rate is between Saffalou-Plateau. In general, this index is less than 50%, it is concluded that the three stations are different and do not share many common species (Yabi *et al*., 2013).

The majority of species are individualized in group 1 (152; 91.56%), these species are annual and perennial herbs and are located in the centre (intersection of the axes). The group 2 reunited 14 species (8.43%), it was found *P. lentiscus* L. (*Pi Le*) where it is very characteristic of the order Pistacio-*Rhamnetalia alaterni* (Rivas-Martinez, 1974), this order brings together the pre-forest structures resulting from an intense degradation of forest formations in which the mastic tree is often associated with *Quercus ilex* (*Qu il*), *Juniperus oxycedrus* (*Ju ox*), *Phillyrea angustifolia* (*Ph an*), *Calicotome spinosa* (*Ca sp*), *Ampelodesmos mauritanicus* (*Am ma*), *Asparagus acutifolius* (*As ac*) and *Lavandula stoechas* (*La st*).

The positive side brings together 50 species or 30.12% of the total, essentially a pre-forest structure species dominated by the tree and shrub layer composed of *P. lentiscus*, *P. angustifolia*, *Q. ilex*, *J. oxycedrus*, *C. spinosa*, L. *stoechas*, *A. mauritanicus*, *Cistus salvifolius*, and the herbaceous layer of *Lobularia maritima*, *Lysimachia arvensis*, *Erodium moschatum*, etc.

The current study examined the floristic diversity and ecological factors influencing *Pistacia lentiscus* plant groups in western Algeria. The results obtained were compared with those of other studies on similar topics, providing a broader understanding of the ecological dynamics and anthropogenic impacts on local ecosystems.

According to the findings of this study, 116 species, accounting for 69.87% of the negative side of the floristic spectrum, were identified, predominantly consisting of annual and perennial herbaceous species such as *Stachys ocymastrum*, *Cleonia lusitanica*, *Convolvulus cantabrica*, *Echium plalltagineum*, *Ammoides pusilla*, *Sanguisorba minor*, *Lysimachia monelli*, and *Atractylis cancellata*. It was also noted that species indicative of environmental degradation, including *Asparagus albus*, *Ferula communis*, *Macrochloa tenacissima*, and *Carduus pycnocephalus*, were present (Babali, 2014). These findings are consistent with those of other researchers who have observed the dominance of short-lived species in areas affected by intense anthropogenic activity.

The dynamic gradient of vegetation in this study revealed a clear distinction between the positive and negative axes. The positive axis was primarily occupied by species typical of pre-forest vegetation structures, while the negative axis showed a dominance of species with short life cycles, a result of significant anthropogenic disturbances. This phenomenon aligns with observations made in earlier studies on *P. lentiscus* populations (Benmehdi, 2012; Benmehdi *et al.*, 2013), which also highlighted the influence of human activities on the vegetation composition. Similar findings were reported by K. Cherifi *et al.* (2011) and S.M. Merioua *et al.* (2013), who attributed the degradation of plant formations in western Algeria to intense anthropozoogenic actions.

Moreover, the results of the present study corroborate the broader trend observed in western Algeria, where anthropogenic pressures have significantly impacted plant communities, leading to the predominance of species adapted to disturbed environments. N. Benabadji *et al.* (2014) emphasised the role of such disturbances in shaping the floristic structure of the region, and similar patterns were observed across various plant formations in the area. Thus, the observed dominance of short-lived species in disturbed areas is a consistent finding in the literature, underlining the broader ecological implications of human activity on Mediterranean ecosystems.

Conclusions

This study provided an overview of the current knowledge on groups of *Pistacia lentiscus L.* and their dynamics in the Tiaret Mountains through an analytical and statistical approach. The vegetation sampling carried out at the three study stations based on 30 floristic surveys allowed to identify 166 species belongs to 43 families of which *Asteraceae*, *Poaceae*, *Fabaceae*, *Cistaceae*, *Lamiaceae* and *Brassicaceae* constitute more than half of the flora studied with 51.1% in total. The life forms of species reveal the dominance of species with a short life cycle with a large presence of therophytes with 51.2%, which reflects slightly high rate of disturbance estimated to 63% overall. The majority of inventoried species are individualised in the first group with 91.56%, while the second group includes the rest of the species with only 8.43.

The eigenvalues and percentage of inertia for the first three axes of the FAC show that first axis (01) represents 28.8% of the majority of the information of which 50 species of the total represented mainly by trees and shrubs are on the positive side of this axis, while 116 species dominated by annual and perennial herbaceous plants are grouped on the negative side of the same axis. This distribution is the result of ecological factors influencing these plant groups in particular the opening of the environment through human practices.

In view of these results, the installation of short-life cycle plants and pyrophytic shrubs promotes the outbreak and spread of forest fires during the summer period, which have become increasingly frequent in recent years in Algeria. Therefore, findings shed light on the therophytic influence of the *P. lentiscus* L. plant community, thus necessitating the adoption of more appropriate firefighting strategies within reforestation and forest fire prevention programs.

Acknowledgements

The authors thank Babali Brahim. PhD in plant ecology from the Laboratory of Ecology and Management of Natural Ecosystems, Tlemcen, Algeria for the confirmation of the identified taxa.

Funding

None.

Conflict of Interest

None.

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Диверсифікація та флористичний аналіз груп *Pistacia lentiscus* L. (Anacardiaceae) у регіоні Тіарет (Західний Алжир)

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Анотація. Метою цього дослідження було вивчення та аналіз груп *Pistacia lentiscus* L., які зустрічаються в регіоні Тіарет. Використовуючи аналітичний і статистичний підходи до флористичних інвентаризацій, проведених у цій місцевості, були вибрані три станції (Саффалу, Плато та Гертуфа) протягом оптимальних вегетаційних сезонів з березня по червень між 2015 та 2018 роками. Було ідентифіковано 166 видів, які належать до 131 роду та 43 родин, з яких переважають ангросперми (98,2 %). Найбільш представленими родинами були Asteraceae, Poaceae, Fabaceae, Cistaceae, Lamiaceae та Brassicaceae, з такими відсотковими співвідношеннями: (15,1 %, 10,8 %, 9 %, 6 %, 5,4 % і 4,8 %) відповідно. Біологічний спектр флори переважно складали терофіти (51,2 %), в той час як група середземноморських видів була добре представлена (54,8 %) порівняно з іншими групами. Розрахунки екологічних індексів показали, що індекс Шеннона вказує на високу різноманітність (H = 4,6), індекс рівномірності Пієлу (J = 0,9) вказує на регулярність у розподілі видів, а індекс Сімпсона (1-D = 0,98) відображає низьку різноманітність стоянок. Загальний індекс порушення (PI = 63 %) вказує на відкритість середовища. Крім того, коефіцієнт подібності Яккарда (S) залишався менше 50 % у всіх композиціях між станціями, що свідчить про гетерогенність флористичного складу цих станцій. Агломеративна ієрархічна класифікація виявила поділ видів на дві основні групи: 91,56 % і 8,43 %. Далі факторний аналіз відповідності відобразив відкриття середовищ на досліджених територіях та поселення видів з коротким життєвим циклом, що адаптуються до місцевих посушливих умов. Отримані результати надають діагноз стану рослинного покриву під впливом екологічних факторів і можуть бути використані лісівниками для покращення управління, захисту та відновлення цих природних територій

Ключові слова: мастикові дерева; флористичне багатство; екологічні фактори; терофітізація; посушливість

Received: 10.07.2025; Revised: 16.10.2025; Accepted: 27.11.2025

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 16(4)

UDC 630.232
DOI: 10.31548/forest/4.2025.57

The effect of spraying with salicylic acid and humic acid on the physiological and chemical qualities of *Acacia cyanophylla* seedlings

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Abstract. Given the growing environmental challenges and the imperative for successful afforestation initiatives, there is an increasing demand for enhancing seedling growth and quality through natural treatments. This study was conducted to evaluate the effects of salicylic acid and humic acid on the physiological and biochemical attributes of *Acacia cyanophylla* seedlings. The experiment was carried out in the nursery of the tourist village of Nineveh forests, where seedlings were sprayed with salicylic acid (0, 200, 400 $mg \cdot L^{-1}$) and humic acid (0, 1, 2 g per seedling) to assess their effects on selected physiological and chemical traits. The results showed that spraying with salicylic acid at 200 $mg \cdot L^{-1}$ had a significant impact on carbohydrate content, protein percentage, total chlorophyll content of leaves, and relative moisture content. Similarly, humic acid at 2 g per seedling produced the highest significant increases in these traits. As for the bilateral interaction between salicylic acid and humic acid, the results showed that spraying with salicylic acid at 200 $mg \cdot L^{-1}$ in combination with humic acid at 2 g per seedling resulted in the highest values for most of the studied traits. This combined application significantly enhanced seedling growth and overall physiological vigor. Foliar application of salicylic acid at 200 $mg \cdot L^{-1}$ resulted in a marked increase in chlorophyll content, thereby promoting photosynthetic efficiency, while humic acid

Suggested Citation:
Aljboore, M., & Alhadedy, S. (2025). The effect of spraying with salicylic acid and humic acid on the physiological and chemical qualities of *Acacia cyanophylla* seedlings. *Ukrainian Journal of Forest and Wood Science*, 16(4), 57-69. doi: 10.31548/forest/4.2025.57.

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application markedly improved leaf water retention, substantially augmenting the seedlings' tolerance to environmental stress. Collectively, these results indicate that the integrated use of salicylic acid and humic acid represents a promising and effective approach for enhancing seedling quality and vigor, particularly in the context of afforestation programs

Keywords: foliar spraying; physiological traits; chemical composition; seedling quality; photosynthetic pigments; afforestation

Introduction

Trees are integral to ecosystem stability and serve as a critical defence against environmental degradation by counteracting desertification, attenuating the effects of climate change, curbing soil erosion, and enhancing air quality. Beyond their ecological functions, forest trees supply vital resources – including fuelwood, fodder, medicinal compounds, and materials for construction. As a result, strategically designed afforestation and reforestation initiatives have emerged as central pillars in global strategies to promote environmental sustainability and resilience. The effectiveness of these initiatives hinges critically on the availability of high-quality seedlings characterised by robust physiological performance and heightened tolerance to abiotic stresses – outcomes that can only be achieved through the implementation of evidence-based nursery cultivation and management practices.

According to O. Kosanin *et al.* (2023) the presence of trees in natural forests or their cultivation is one of the most important factors that affect the ecosystem and resist desertification, global warming, dust storms, a source of fuel, medical materials, animal feed, and building materials, prevent soil erosion, and reduce the destructive effects of flood seasons. Well-planned tree planting projects are an important element in global efforts to improve environmental and humanitarian conditions, but tree planting must be in accordance with well-thought-out scientific plans to overcome environmental problems facing the climate and the environment. K.D. Holl & P.H.S. Brancalion (2020) noted that one of the species that is preferred for cultivation is *Acacia cyanophylla*, which belongs to the leguminous family. It is a thornless, evergreen, dangling, fast-growing shrub with branches up to 7 meters high and can reach 10 meters. Its leaves are thick, smooth, waxy and blue-green. The lower leaves are larger than the upper leaves, the flowers are bright golden-coloured, spherical, clustered every 3-5 of them in a cluster.

A. Kheloufi *et al.* (2019) reported that *Acacia cyanophylla* is highly valued for ornamental landscaping, particularly in gardens, urban green spaces, and roadside plantings, due to its attractive yellow inflorescences and persistent evergreen foliage. The authors also emphasised the species' broad geographical distribution, noting its presence in numerous Arab countries. Furthermore, their study indicated that mature plants exhibit moderate tolerance to salinity and drought stress, primarily propagate via seeds, and possess limited capacity for vegetative propagation. F. Marzialetti *et al.* (2019) observed that *Acacia cyanophylla* is native to Australia and is extensively cultivated for multiple purposes, including firewood production and environmental applications such as sand dune stabilisation and windbreak establishment. In efforts to improve afforestation success under field conditions, the application of plant growth-regulating compounds has gained increasing research attention.

Salicylic acid – a naturally occurring plant hormone present in trace amounts in plant tissues – plays a critical role in plant defense against pathogens and in adaptation to various abiotic stresses, including drought, heavy metal toxicity, extreme temperatures, and osmotic stress. As demonstrated by N.N. Parihar & V. Shelar (2023), salicylic acid functions as an effective growth regulator, positively influencing a range of physiological and biochemical processes such as seed germination, respiration, vegetative growth, flowering, and photosynthetic activity. A. Dauletbay *et al.* (2024) examined the properties, structure, and agricultural uses of humic substances and found that these compounds substantially enhance soil fertility by improving soil structure, boosting cation exchange capacity, modulating soil pH, and promoting the activity of beneficial soil microorganisms. L.P. Canellas *et al.* (2020) reported that humic substances function as chemical priming agents in plants, affecting cellular metabolism – particularly in cell walls, membranes, and the cytoplasm. Their research demonstrated that humic acids increase photosynthetic efficiency, respiration rates, and protein synthesis through hormone-like effects. Additionally, K. Ampong *et al.* (2022) confirmed that humic acids indirectly promote plant growth by enhancing nutrient availability and uptake, primarily by stimulating microbial activity in the rhizosphere, thereby facilitating the absorption of essential mineral nutrients.

Based on the importance of this plant species in forests as well as gardens or in the afforestation of roads, the impact of both salicylic acid and humic acid on the vitality and productivity of *Acacia cyanophylla* seedlings was decided to be investigated in this study. The goal of this study was to evaluate the effects of salicylic acid and humic acid on the physiological and biochemical attributes of *Acacia cyanophylla* seedlings, particularly focusing on their influence on seedling growth, stress tolerance, and overall vigor.

Materials and Methods

The experiment was carried out in the area of the tourist village inside the forests of Nineveh at the intersection of a latitude of (36°22’42’’) north, a longitude of (43°70’60’’) east, and at an altitude of 219 m above sea level. For the period from (September 2024 to September 2025), laboratory analyses were conducted within the Development Laboratory of the Forestry Science Department. The study site was chosen to establish a young tree on an area of 2 dunums within the tourist village, where cleaning operations were carried out for the study site of tree waste, jungle and wood pieces scattered within the site and regular modification and levelling of the land. The jungle was controlled with specialised pesticides to eliminate it. Planting sites for seedlings and the drilling corps were planned within the site at equal distances and depths of more than 50 cm according to the field experiment scheme. An organised distillation network was extended on the drilling. Distillation nozzles were placed at each hole and the distillation system was connected with the water source (artesian well) within the site. Planting of seedlings was carried out at the beginning of the ninth month and regular maintenance and watering operations continued throughout the study period.

The seedlings were brought from the Umm Al-Rubaieen nursery of the Department of Horticulture and Garden Engineering in the Farms District, which is one of the government nurseries affiliated with the Ministry of Agriculture. The seedlings were one year old with consistent and equal lengths and diameters and were planted in black polyethylene bags with a diameter of 10 cm and a length of 30 cm per bag. The height of the seedlings inside the bag was about 70 cm. The seedlings were planted from seeds sourced from a number of growing trees inside the nursery. The seedlings were brought to the study site with a number of (324 seedlings), and the seedlings were planted inside the pits designated for them. Watering and cleaning operations for the bush were carried out on a regular basis throughout the study period.

Experimental factors:

Factor I: Salicylic acid (400,200,0) $mg \cdot L^{-1}$;

Factor II: Humic acid (2,1,0) $g \cdot L^{-1}$.

The experiment comprised nine treatment combinations, each including six seedlings, arranged in three replications according to a randomised complete block design (RCBD). Statistical analysis was performed using SAS software (version 9.0), and treatment means were compared using Duncan's multiple range test at a significance level of $P \leqslant 0.05$ (Dafaallah, 2019). The evaluation of seedling response to the applied treatments was based on the assessment of selected physiological and biochemical parameters related to water status, photosynthetic capacity, and metabolic activity. Accordingly, relative leaf water content, carbohydrate concentration, total protein percentage, and total chlorophyll content were determined using standard analytical methods.

Relative moisture content of leaves (%). The moisture content of the leaves was estimated according to M.R.B. Siddique *et al.* (2000), where 20 leaves were weighed for each seedling in the experimental unit, and they were directly wet with a sensitive scale with a sensitivity of 0.01. Their wet weight was recorded, then they are immersed in distilled water for 16-18 hours at room temperature 23-25°C and under low lighting conditions in order to saturate the leaves with distilled water. Their swell weight is recorded in the case of saturation Turgid Weight, then the leaves are dried in the oven at a temperature of $70^{\circ} \pm 1$ and until the weight was fixed and the dry weight was recorded, then the relative moisture content of the leaves was calculated for each transaction A.G. Konings *et al.* (2021) according to the following mathematical relationship:

$$\text{relative water content of the leaves} = \\ = \frac{\text{wet weight} - \text{dry weight of the leaf}}{\text{turgid weight} - \text{weight of the leaf}} \times 100. \quad (1)$$

Estimation of carbohydrate content of leaves ($mg \cdot g^{-1}$ dry weight). The content of carbohydrates in the leaves was estimated according to the method of M. Dubois *et al.* (1956) by taking a weight of 0.1 g of dry leaves, where they were crushed in a ceramic mortar and added 10 ml of distilled water, then the solution is taken and placed in a test tube and placed in a centrifuge for 15 minutes at a speed of 3,000 cycles/minute, after which the filtrate is taken and a distilled water mechanism is added for the purpose of completing the volume to 10 ml, then it was taken 1 ml of the solution and add 1 ml of phenol at a concentration of 5%, then add 5 ml of concentrated sulfuric acid H_2SO_4 and leave the sample for (15) minutes, then put in a water bath at a temperature of (25-30)° for a period of 20 minutes , after which the absorption is read using a spectrophotometer at a wavelength of 488 nm, and the readings are dropped on the standard curve of glucose sugar to obtain the concentration of carbohydrate as mentioned by D. Herbert *et al.* (1971):

$$\text{Carbohydrates (mg/g)} = \\ = \frac{\text{Volume of extract used} \times \text{Total extract volume} \times \text{Read device}}{\text{Sample weight} \times 1000}. \quad (2)$$

Estimating the percentage of total protein in the leaves. Total protein content in the leaves was determined by weighing 0.1 g of dried leaf material, which was finely ground using a ceramic mortar. The sample was mixed with 10 mL of distilled water and centrifuged for 15 min at 3,000 rpm. The supernatant was collected, and distilled water was added to adjust the final volume to 10 mL. From this extract, 1 mL was taken and mixed with 20 µL of a ready-to-use analysis kit (Fortress Diagnostics, UK).

Protein determination was based on the Biuret method, which relies on the formation of a violet-coloured complex resulting from the reaction between proteins and copper ions in an alkaline medium. The intensity of the colour, proportional to protein concentration, was measured spectrophotometrically at a wavelength of 550 nm, following the method described by C.A. Burtis & E.R. Ashwood (1999). The reagents used included a Biuret reagent composed of sodium hydroxide (200 $\text{mmol}\cdot\text{L}^{-1}$), copper sulphate (18 $\text{mmol}\cdot\text{L}^{-1}$), and sodium potassium tartrate (32 $\text{mmol}\cdot\text{L}^{-1}$), as well as a standard protein solution prepared at a concentration of 6 g per 100 mL. Total protein concentration was calculated according to the following equation:

$$\text{Total protein (g dL}^{-1}) = \text{Total protein (g/dl)} \frac{\text{A sample}}{\text{Astandra}} \times \text{standard concentration}, \qquad (3)$$

where *A* represents absorbance intensity and 1 dL = 100 mL.

Estimation of total chlorophyll content in leaves ($\text{mg}\cdot\text{g}^{-1}$ soft vegetable fabric). Chlorophyll a and b and total chlorophyll were estimated based on the Mackinney. Leaves were taken from the developing top of three samples of *Acacia cyanophyll* seedlings and then cut to facilitate the estimation process. Then a weight of 0.2 g of healthy soft green leaves was taken. The leaves were crushed by a ceramic mortar and then acetone 12 ml was added to the concentration (80%). After that, they were placed in the centrifuge for 5 minutes at a speed of 3,000 cycles/minute for the purpose of separating the leachate from the precipitate. The leachate was then taken and the absorbency was read at wavelengths 645, 663 nm by the spectrophotometer. The following equations were used to calculate the amount of chlorophyll in the leaves calculated on the basis of ($\text{mg}\cdot\text{g}^{-1}$ wet weight).

$$\text{Total Chlorophyll} = [20.2\,(\text{D}645) + 8.02\,(\text{D}663)] \times \text{V}/1000 \text{ x W}, \qquad (4)$$

where V = final volume of leachate after completion of separation by centrifuge, D = read the photodensity (absorptivity) of the extracted chlorophyll, W = mild weight in g. All research procedures involving plant material were conducted in compliance with international ethical standards and relevant regulations, in accordance with the principles of the Convention on Biological Diversity (1992).

Results

Relative moisture content of leaves (%). The results of Table 1 regarding the relative moisture content of the leaves showed significant differences between the concentrations of humic acid according to Duncan's test. Where the concentration was recorded 2 $\text{g}\cdot\text{L}^{-1}$ The highest moral increase in this characteristic amounted to 74.74% while the concentration recorded 0 $\text{g}\cdot\text{L}^{-1}$ The lowest moral value reached 72.21% with a moral difference of 2.53%. As for the concentrations of salicylic acid, Duncan's test showed significant differences between the concentrations and gave the concentration 400 $\text{mg}\cdot\text{L}^{-1}$. The highest intangible value of 76.99% compared to the concentration of 0 $\text{mg}\cdot\text{L}^{-1}$, which gave the lowest rate of 71.63% with a moral difference of 5.36%.

Table 1. The effect of spraying with salicylic acid and humic acid and the overlaps between them in the relative moisture content of the leaves (%)

		Salicylic acid concentrations $\text{mg}\cdot\text{L}^{-1}$			Effect of humic acid $\text{mg}\cdot\text{L}^{-1}$
		0	200	400	
Humic acid concentrations $\text{mg}\cdot\text{L}^{-1}$	0	69.73 i	75.58 d	77.35 b	72.21 b
	1	71.64 h	77.23 c	73.88 e	74.24 a
	2	73.55 f	78.18 a	72.52 g	74.74 a

Table 1, Continued

	Salicylic acid concentrations $mg \cdot L^{-1}$			Effect of humic acid $mg \cdot L^{-1}$
	0	200	400	
Effect of salicylic acid $mg \cdot L^{-1}$	71.64 c	76.99 a	74.58 b	

Note: numbers with similar letters for individual factors and their overlaps do not differ significantly between them according to Duncan's polynomial test at a probability level of 0.05
Source: developed by the authors

As the bilateral overlap between the concentrations of salicylic acid and the concentrations of humic acid showed, Duncan's test indicated significant differences between the concentrations in this characteristic, and between the overlap between salicylic acid 200 $mg \cdot L^{-1}$ and humic acid 2 $g \cdot L^{-1}$ has the highest significant value among the overlaps of the factors and gave the highest significant value of 78.18% compared to the treatment of the overlap of salicylic acid 0 $mg \cdot L^{-1}$ and humic acid (0 $g \cdot L^{-1}$, which recorded the lowest rate of 69.73% with a moral difference of 8.45%.

Estimation of the carbohydrate content of leaves ($mg \cdot g^{-1}$ dry weight). The results of Table 2 showed the effect of humic acid concentrations, as they differed significantly in the effect on the leaf content of carbohydrates and reached the highest rate at the concentration of 1 $g \cdot L^{-1}$, which amounted to 25.00 $mg \cdot L^{-1}$ dry weight for the lowest intangible value found at the concentration 0$mg \cdot L^{-1}$ dry weight, which amounted to 24.07 $mg \cdot L^{-1}$ dry weight with a moral difference of 0.73%.

Table 2. The effect of spraying with salicylic acid and humic acid and the overlaps between them in the characterisation of the leaf content of carbohydrates ($mg \cdot g^{-1}$ dry weight)

		Salicylic acid concentrations $mg \cdot L^{-1}$			Effect of humic acid $g \cdot L^{-1}$
		0	200	400	
Humic acid concentrations $g \cdot L^{-1}$	0	21.84 i	24.77 e	25.62 c	24.07 b
	1	22.60 h	25.75 b	24.82 d	24.39 b
	2	23.33 g	26.96 a	24.73 f	25.00 a
Effect of salicylic acid $mg \cdot L^{-1}$		22.59 c	25.82 a	25.05 b	

Note: numbers with similar letters for individual factors and their overlaps do not differ significantly between them according to Duncan's polynomial test at a probability level of 0.05
Source: developed by the authors

With regard to the effect of salicylic acid, the data of Table 2 of the Duncan's test showed significant differences between the concentrations and the concentration of 400 $mg \cdot L^{-1}$, the highest moral increase of 25.02 $mg \cdot L^{-1}$ dry weight compared to the comparison treatment with a concentration of 0 $mg \cdot L^{-1}$ dry weight, which gave the lowest rate of 22.59 $mg \cdot L^{-1}$ dry weight with a moral difference of 2.43%. Table 2 of the Duncan's test between the concentrations of salicylic acid and the concentrations of humic acid showed that there were significant differences between the concentrations in this interference ,and between the interference between salicylic acid 200 $mg \cdot L^{-1}$ and humic acid 2 $g \cdot L^{-1}$ recorded the highest moral increase among the interactions of the factors, which amounted to 26.96 $mg \cdot L^{-1}$ dry weight compared to interferometric treatment salicylic acid 0 $mg \cdot L^{-1}$ and humic acid 0 $g \cdot L^{-1}$, which recorded the lowest rate of increase, amounting to 21.84 mg · L^{-1} of dry weight with a moral difference of 5.12%.

Estimating the leaf content of total proteins (%). Table 3 indicates that there are significant differences between the concentrations of humic acid in the character of the leaf content of proteins according to the Duncan' test. Where the concentration was recorded 1 g · L^{-1} The highest moral increase in this characteristic amounted to 6.40% while the concentration recorded 0 g · L^{-1} The lowest moral value was 6.08% with a moral difference of 0.32%. As for the concentrations of salicylic acid, Duncan's test showed Table 3 that the concentration is 200 mg · L^{-1} and concentration 400 mg · L^{-1} recorded the highest rates, respectively 6.44 and 6.45%, but they did not differ significantly between them, but they outperformed the comparison treatment with a concentration of 0 mg · L^{-1}, which gave the lowest increase of 5.17% with a moral difference of 1.27 and 1.28%.

Table 3. The effect of spraying with salicylic acid and humic acid and the overlaps between them in the character of the leaf content of total proteins (%)

		Salicylic acid concentrations mg · L^{-1}			**Effect of humic acid g · L^{-1}**
		0	**200**	**400**	
Humic acid concentrations g · L^{-1}	0	5.65 h	6.18 e	6.39 c	6.08 b
	1	5.36 i	6.24 d	6.77 b	6.12 a
	2	6.11 g	6.92 a	6.17 f	6.40 a
Effect of salicylic acid mg · L^{-1}		5.17 b	6.45 a	6.44 a	

Note: numbers with similar letters for individual factors and their overlaps do not differ significantly between them according to Duncan's polynomial test at a probability level of 0.05
Source: developed by the authors

Between the bilateral overlap between the concentrations of salicylic acid and the concentrations of humic acid, the Duncan's test Table 3 showed significant differences between the concentrations in this characteristic ,and the overlap between salicylic acid 200 mg · L^{-1} and humic acid 2 g · L^{-1} has the highest significant value among the overlaps of the factors, which amounted to 6.92% compared to the treatment of the overlap with salicylic acid 0 mg · L^{-1} and humic acid 0 g · L^{-1}, which recorded the lowest rate of 5.65% with a moral difference of 1.27%.

Estimation of the total chlorophyll content of leaves (mg·g^{-1} soft weight). The results of Table 4 regarding the total chlorophyll content of the leaves indicated that there are significant differences between the concentrations of humic acid according to the Duncan's test, where the concentration was recorded 1 g · L^{-1}. The highest moral increase in this characteristic amounted to 1.48 g · L^{-1} g soft weight while the concentration was recorded 0 g · L^{-1} with a minimum intangible value of 1.30 g · L^{-1} of soft weight with a significant difference of 0.18%.

Table 4. The effect of spraying with salicylic acid and humic acid and the overlaps between them in the character of the total chlorophyll content of the leaves (mg · g^{-1} soft weight)

		Salicylic acid concentrations mg · L^{-1}			**Effect of humic acid mg · L^{-1}**
		0	**200**	**400**	
Humic acid concentrations g · L^{-1}	0	1.22 i	1.38 f	1.46 b	1.35 c
	1	1.33 h	1.46 c	1.45 d	1.41 b
	2	1.34 g	1.60 a	1.44 e	1.46 a

Table 4, Continued

0	Salicylic acid concentrations mg · L^{-1}			Effect of humic acid mg · L^{-1}
	200	400		
Effect of salicylic acid mg · L^{-1}	1.30 b	1.48 a	1.45 a	

Note: numbers with similar letters for individual factors and their overlaps do not differ significantly between them according to Duncan's polynomial test at a probability level of 0.05
Source: developed by the authors

The Duncan's test (Table 4) showed that the concentration is 200 mg · L^{-1} and concentration 400 mg · L^{-1} recorded the highest rates, respectively 1.44 and 1.48 mg · L^{-1} of soft weight, but they did not differ significantly between them, but they outperformed the comparison treatment with a concentration of 0 mg · L^{-1}, which gave the lowest increase of 1.30 mg · L^{-1} of soft weight and a significant difference of 0.14, 0.18, respectively. The bilateral overlap between the concentrations of salicylic acid and the concentrations of humic acid in the Dunkin's test Table 4 showed that there are significant differences between the entries in this trait ,as the overlap between salicylic acid 200 mg · L^{-1} and humic acid 2 g · L^{-1} gave the highest significant value between the overlaps of the factors and gave the highest significant value of 1.60 mg · L^{-1} soft weight compared to interferometric treatment salicylic acid 0 mg · L^{-1} and humic acid 0 g · L^{-1}, which recorded the lowest rate of 1.22 mg · L^{-1} of soft weight with a significant difference of 0.38%.

The results showed that spraying with humic acid had a significant impact on the physiological and chemical qualities of *Acacia cyanophylla* seedlings as clear differences were recorded between the transactions, indicating that the seedlings were affected by spraying with humic acid. It was found that the spraying was at a concentration of 2 g · L^{-1} led to a significant increase in the rates of the studied traits (relative moisture content, carbohydrate percentage, total protein percentage, leaf content of LeRovell). The data also showed that the spray was 0 mg · L^{-1} led to a decrease in the rates of the studied traits. This is attributed to the fertilisation processes with humic acid in plants, which increases chlorophyll in the leaves and encourages growth, increases the size of cells, and vegetative properties. The effect of humic acid due to its containment of oxygen, hydrogen, carbon, and nitrogen in varying proportions and with light molecular weights when used for plants, plays an essential role in feeding plants, which is reflected in photosynthesis, increased proteins, increased carbohydrates, and respiration. In addition, humic substances contribute to raising the internal levels of plant hormones, such as oxines and gibrilins, by stimulating their formation or preventing their decomposition. The reason behind the increase in vegetative growth indicators and plant chemical content may be that humic substances increase the proportion of oxygen-rich solid compounds in cells. The results are consistent with those reported by F.S. Al-Marsoumi (2019), who investigated the foliar application of three concentrations of humic acid (0, 1, and 2 g · L^{-1}) on seedlings of the 'Qalb al-Thawr' mango cultivar (*Mangifera indica* L.). The findings revealed that the 2 g · L^{-1} concentration significantly outperformed other treatments across two consecutive growing seasons, yielding the highest values for plant height increase (47.9 and 39.1 cm), stem diameter (4.68 and 9.24 mm), leaf number (65.8 and 89.3 leaves · plant^{-1}), and branch number (4.33 and 7.83 branches), while the control treatment produced the lowest values for all measured traits. These findings also align with the study conducted by F.S. Al-Marsoumi & M.E.A. Al-Hadethi (2020) on one-year-old mango seedlings *Mangifera indica* L., in which foliar application of humic acid at concentrations of 0, 1, and 2 $mL \cdot L^{-1}$ significantly enhanced leaf nutrient content. Specifically, the 2 $mL \cdot L^{-1}$ treatment resulted in the highest leaf nitrogen content (1.403% and 1.743%), potassium content (0.520% and 0.463%), iron content (190.6 and 235.3 ppm), and zinc content (44.46 and 51.38 ppm) during the two consecutive seasons, respectively.

Furthermore, the current results are in agreement with N. Vikram *et al.* (2022), who described humic acids as complex organic compounds derived from the decomposition of organic matter in soil. These substances play a pivotal role in regulating various biological and environmental processes. They improve soil structure, enhance water and nutrient retention capacity, stimulate plant growth and beneficial microbial activity, and effectively modulate nitrogen and carbon cycling – thereby enhancing the overall efficiency and sustainability of agricultural ecosystems. The findings also corroborate those of H.M. Ibraheem (2021), who evaluated the effect of organic fertiliser application on the growth of *Pinus pinea* L. seedlings. In that study, seedlings were foliar-sprayed with four concentrations (0, 1, 2, and 3 $g \cdot L^{-1}$) of organic fertiliser. The results demonstrated that all treated seedlings exhibited significant improvements in all measured growth parameters compared to the control. Notably, the 2 $g \cdot L^{-1}$ concentration was statistically superior across all evaluated traits relative to the untreated control.

As for the effect of salicylic acid concentrations on some of the vegetative traits studied for pine protein seedlings, the results of Tables 1-4 indicate that there are differences between the concentrations and it has a significant impact, especially at the concentration of 400 $mg \cdot L^{-1}$ compared to the comparison treatment. The reason may be that salicylic acid plays an important role in regulating physiological and biological processes (Song *et al.,* 2023), and is considered one of the most important compounds responsible for promoting plant health and resistance to harmful environmental conditions. Promotes cell division and elongation, which contributes to increased vegetative growth, stimulates metabolic reactions such as protein and carbohydrate synthesis, and increases chlorophyll levels in leaves and leaf water content, improving photosynthetic efficiency and energy production. Contributes to the improvement of gas exchange by regulating the opening and closing of stomata, as noted by J.D. Vashi (2023). It also reduces the harmful effects of water shortage by regulating osmotic pressure and increasing drought resistance, and contributes to protecting plants from high temperatures by promoting an antioxidant system that promotes the movement of nutrients such as nitrogen, phosphorus, and potassium towards the aerial parts of the plant, improving growth and productivity and interacting with other plant hormones (such as oxines and gibellins) to regulate vital processes These results also consistent with those reported by A.H. Alalaf & M.M. Ibrahim (2020), who investigated the foliar application of salicylic acid at three concentrations (0, 200, and 400 $mg \cdot L^{-1}$) on papaya (*Carica papaya* L.) seedlings. The results demonstrated that the 200 $mg \cdot L^{-1}$ treatment significantly enhanced seedling height increase, while the 400 $mg \cdot L^{-1}$ concentration yielded the highest values for vegetative growth parameters and leaf content of nitrogen, potassium, and phosphorus. In contrast, the control treatment (0 $mg \cdot L^{-1}$) recorded the lowest significant values across all evaluated traits.

These results also align with the study by S.A. Hussein & H.S. Kanber (2024), who examined the effect of foliar-applied salicylic acid at concentrations of 0, 100, and 200 mg · L^{-1} on fig (*Ficus carica* L.) seedlings. Their findings indicated that the 200 mg · L^{-1} treatment produced the greatest plant height, leaf area, and leaf number, suggesting a pronounced growth-promoting effect of salicylic acid on seedling development. Furthermore, the present outcomes are in agreement with J.A. Linné *et al.* (2025), who studied the response of seedlings of the endangered species *Cedrela fissilis* Vell. to foliar applications of salicylic acid at 100, 200, and 300 mg · L^{-1}. Their results showed that the 200 mg · L^{-1} concentration induced the most favourable vegetative and root growth responses, significantly outperforming the other concentrations, which yielded comparatively lower values for the measured parameters. Additionally, the results corroborate those of L.C. Saracho *et al.* (2021), who evaluated the impact of salicylic acid on *Schinus terebinthifolia* seedlings subjected to varying irrigation regimes. Using concentrations of 0, 50, 100, and 200 mg · L^{-1}, they found that the 200 mg · L^{-1} treatment produced the highest stem length (20.74 cm) and leaf area (116.04 cm^2), along with the greatest dry mass accumulation in stems, leaves, and roots. These parameters were significantly superior to those observed under lower concentrations or the untreated control.

The results of this study highlight the significant role of salicylic acid and humic acid in enhancing the physiological and biochemical properties of seedlings. These compounds, through their effects on growth regulation and stress tolerance, improve seedling vigor and resilience under challenging environmental conditions. The observed interactions between salicylic acid and humic acid further emphasise their synergistic potential in promoting plant health. Overall, these findings suggest that the application of these biostimulants can be an effective strategy for improving seedling establishment and growth in afforestation projects.

Conclusions

The present study conclusively demonstrates that foliar application of salicylic acid and humic acid significantly enhances the physiological and biochemical attributes of *Acacia cyanophylla* seedlings under nursery conditions. The experimental findings revealed that both growth-regulating compounds, either individually or in combination, exerted a pronounced positive influence on key indicators of seedling vigor, including relative leaf water content, carbohydrate accumulation, total protein synthesis, and chlorophyll concentration. Notably, the optimal response was consistently observed when seedlings were treated with 200 mg · L^{-1} of salicylic acid in conjunction with 2 g · L^{-1} of humic acid, underscoring the existence of a synergistic interaction between these two biostimulants. This combination maximised the expression of all measured traits, suggesting that integrated application strategies may offer superior benefits compared to the use of either compound alone.

The improvement in relative leaf water content reflects enhanced cellular hydration and osmotic adjustment, which are critical for drought resilience particularly relevant given *A. cyanophylla* intended use in arid and semi-arid afforestation projects. The significant increases in carbohydrate and protein content further indicate elevated metabolic activity and improved photosynthetic efficiency, likely mediated through salicylic acid's role in modulating stress-responsive pathways and humic acid's capacity to stimulate enzymatic and hormonal activity. Moreover, the elevated chlorophyll levels observed in treated seedlings correlate with greater photosynthetic potential and overall plant health, aligning with established mechanisms by which humic substances enhance nutrient uptake and chloroplast function.

These results collectively affirm that exogenous application of salicylic and humic acids serves as an effective cultural practice to bolster seedling quality prior to out planting. Given the species' ecological and ornamental value particularly in urban greening, roadside planting, and soil stabilisation initiatives such pre-planting interventions can significantly improve establishment success in challenging environments. Therefore, it is recommended that nursery protocols for *A. cyanophylla* incorporate foliar sprays of 200 $mg \cdot L^{-1}$ salicylic acid and 2 $g \cdot L^{-1}$ humic acid as a standard practice to optimise seedling performance. Future research should explore the carry-over effects of these treatments post-transplantation and under field stress conditions to validate their long-term efficacy in real-world afforestation programs.

Acknowledgements

The authors would like to express their gratitude to the University of Mosul for assisting in overcoming the obstacles encountered, as well as to the College of Agriculture and Forestry at the University of Mosul for facilitating all matters related to the study.

Funding

None.

Conflict of Interest

None.

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Вплив обробки саліциловою кислотою та гуміновою кислотою на фізіологічні та хімічні якості сіянців *Acacia cyanophylla*

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Анотація. З огляду на зростаючі екологічні виклики та необхідність успішних ініціатив з озеленення, зростає попит на покращення росту та якості сіянців за допомогою природних обробок. Це дослідження було проведено для оцінки впливу саліцилової кислоти та гумінової кислоти на фізіологічні та біохімічні характеристики сіянців *Acacia cyanophylla*. Експеримент проводився в розсаднику туристичного селища лісів Ніневії, де сіянці обробляли саліциловою кислотою (0, 200, 400 $мг \cdot л^{-1}$) та гуміновою кислотою (0, 1, 2 г на сіянця) для оцінки їхнього впливу на обрані фізіологічні та хімічні ознаки. Результати показали, що обробка саліциловою кислотою при концентрації 200 $мг \cdot л^{-1}$ мала значний вплив на вміст вуглеводів, відсоток білка, загальний вміст хлорофілу в листках та відносний вміст вологи. Аналогічно, гумінова кислота при дозі 2 г на сіянця призвела до найвищих значних збільшень цих характеристик. Щодо взаємодії саліцилової кислоти та гумінової кислоти, результати показали, що обробка саліциловою кислотою при концентрації 200 $мг \cdot л^{-1}$ у поєднанні з гуміновою кислотою 2 г на сіянця призвела до найвищих значень для більшості досліджених ознак. Така комбінована обробка значно покращила ріст сіянців та загальний фізіологічний потенціал. Листова обробка саліциловою кислотою при концентрації 200 $мг \cdot л^{-1}$ спричинила помітне збільшення вмісту хлорофілу, що сприяло підвищенню фотосинтетичної ефективності, тоді як обробка гуміновою кислотою значно покращила утримання води в листках, значно підвищуючи стійкість сіянців до екологічного стресу. Загалом, ці результати свідчать, що інтегроване використання саліцилової кислоти та гумінової кислоти є перспективним та ефективним підходом для покращення якості та життєздатності сіянців, особливо в контексті програм озеленення

Ключові слова: листова обробка; фізіологічні характеристики; хімічний склад; якість сіянців; фотосинтетичні пігменти; озеленення

Received: 01.08.2025; Revised: 03.11.2025; Accepted: 27.11.2025

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 16(4)

UDC 630.2:581.52
DOI: 10.31548/forest/4.2025.70

Invasion hotspots in wilderness zones of tropical national parks

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Abstract. Invasive alien plant species increasingly threaten the integrity of forest ecosystems in protected areas, particularly within poorly studied wilderness zones of tropical national parks. The aim of this study was to assess the spatial distribution and invasion intensity of invasive alien plant species in the wilderness zone of Gunung Ciremai National Park, West Java, Indonesia. During the wet season, a comprehensive geographical investigation was conducted using twelve systematically established plots (20 × 20 m) with nested subplots representing different growth stages. A total of 18 invasive alien plant species belonging to nine families were recorded. Hierarchical cluster analysis identified three statistically distinct invasion intensity zones: a moderately invaded zone (67% of plots) dominated by Panicum maximum and Isachne globosa; a highly invaded zone (25% of plots) characterised by strong dominance of the woody legume Calliandra calothyrsus; and a low-invasion zone (8% of plots) with minimal establishment. Between-cluster Bray-Curtis dissimilarity (0.72 ± 0.18) exceeded within-cluster values (0.52-0.65), indicating pronounced compositional differentiation. A corridor-based invasion pattern was supported by a significant decline in invasion intensity with increasing

Suggested Citation:
Nasihin, I., Adhya, I.,& Hendrayana, Ya. (2025). Invasion hotspots in wilderness zones of tropical national parks. *Ukrainian Journal of Forest and Wood Science*, 16(4), 70-88. doi: 10.31548/forest/4.2025.70.

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distance from trails ($R^2 = 0.78$, $p < 0.001$). The study provided the first quantitative spatial assessment of invasive plant distribution in wilderness zones of Indonesian protected areas and demonstrated the value of multivariate analyses for identifying invasion hotspots and informing targeted management strategies

Keywords: biological invasion; Bray-Curtis dissimilarity; cluster analysis; protected areas; spatial patterns

Introduction

Invasive alien plant species (IAPS) represent a growing threat to forest ecosystems worldwide, undermining biodiversity, altering community structure, and challenging the effectiveness of conservation efforts in protected areas. Although national parks are established to safeguard ecological integrity, human activities such as recreation, trail development, and landscape modification can facilitate the introduction and spread of invasive species even in zones designated for strict protection. Wilderness areas, often perceived as relatively undisturbed, remain particularly vulnerable due to limited monitoring and the assumption of natural resistance to biological invasions. As a result, the spatial dynamics and drivers of invasive plant establishment in these areas remain insufficiently understood, especially within tropical forest ecosystems.

K. Utkhamthiang *et al*. (2025) assessed the severity and spatial distribution of invasive plant species along a nature trail within the Doi Chiang Dao Biosphere Reserve in northern Thailand. Their study demonstrated that invasion intensity increased in proximity to recreational trails, highlighting the role of anthropogenic disturbance as a key driver of invasive species spread in protected forest ecosystems. The authors emphasised the importance of trail-based monitoring for early detection and management of biological invasions in conservation areas. Developments in spatial ecology have enhanced the understanding of invasion dynamics in protected forests. S.E.N. Pang *et al.* (2023) demonstrated that clustering analysis can reveal spatially associated species patterns and invasion hotspots that are not captured by traditional diversity indices. Likewise, M. Wang *et al.* (2024) showed that functional traits and phylogenetic relationships jointly shape species distributions through environmental filtering and dispersal limitation. Together, these studies suggested that invasion patterns in wilderness zones result from complex interactions between anthropogenic disturbance and natural ecological processes rather than from a single driver.

In their review, H.D. Flickinger & J.S. Dukes (2024) compared theoretical approaches to invasion ecology and the shifting of species ranges induced by climate change. They provided an overview of existing theories that combine these two aspects, highlighting the importance of considering climate change as a key driver for understanding invasion mechanisms. The paper was significant for studies addressing invasive species, as it bridged the concepts of climate change and invasion dynamics, which are crucial for managing forest ecosystems in response to emerging threats. Climate change adds a layer of vulnerability to montane protected areas. A. Poudel *et al.* (2024) predicted that rising temperatures will allow highly invasive species to colonise higher elevations previously constrained by climate. Advances in invasion detection methodologies have improved spatial assessment capabilities. R. Sengupta & S.S. Dash (2024) demonstrated that species distribution modelling can effectively identify invasion hotspots and support targeted monitoring efforts in data-limited regions. P.B. Rakgoale & S.N. Ngetar (2024) further showed that integrating remote sensing with machine learning and deep learning substantially improves the detection accuracy of invasive species at landscape scales. I. Kim *et al.* (2025) emphasised that native forest structure and species diversity strongly influence invasive plant richness and invasion resistance. Despite these methodological advances, ground-based field data remain indispensable, particularly in remote wilderness zones where satellite-based detection is constrained by dense canopy cover and complex forest structure.

J. Chen *et al.* (2024) explored the application of ensemble learning algorithms to improve the performance of forest age prediction models using satellite remote sensing data. They demonstrated that by combining multiple learning algorithms, it is possible to enhance the accuracy of age predictions for forest ecosystems, which is crucial for forest management and monitoring. The study effectively highlighted the potential of remote sensing data and machine learning techniques in ecological research, specifically in predicting forest parameters, such as age, which is directly relevant to understanding forest dynamics and ecosystem health. P.E. Hulme (2024) identified international tourists as significant biosecurity pathways into national parks, emphasising that recreation intensity and visitor movement patterns are critical factors influencing invasion dynamics alongside physical infrastructure. Despite growing research interest, substantial knowledge gaps persist. Most invasion studies focus on easily accessible areas, leaving wilderness zones largely understudied, particularly in tropical Southeast Asia. Few investigations apply multivariate spatial analyses to test corridor-invasion hypotheses using fine-scale data from strictly protected areas. L. Petri & I. Ibáñez (2025) demonstrated that effective invasive species management can facilitate native plant recovery, underscoring the importance of understanding current invasion patterns to inform restoration strategies. These gaps highlight the need for integrated spatial assessments combining field surveys, cluster analysis, and distance-based modelling in tropical montane wilderness zones.

The aim of this study was to assess the spatial distribution, invasion intensity, and trail-related drivers of invasive alien plant species in the wilderness zone of Gunung Ciremai National Park (GCNP), Indonesia. The objectives were to: (1) document species diversity across growth stages; (2) detect spatial heterogeneity using cluster analysis; and (3) quantify relationships between invasion patterns and disturbance gradients. Invasion intensity was hypothesised to decline with increasing distance from trails, and clustering revealed successional zones.

Materials and Methods

Study site and environmental context. Research was conducted in GCNP wilderness zone, West Java, Indonesia (6°46’57”-6°58’57” S, 108°19’18”-108°29’30” E). GCNP is a 15,500-ha mountain forest ecosystem on Java’s highest single volcano (3,078 masl). The study area altitude ranged from 928 to 1,040 m with slopes of 30-65% (Fig. 1). The average annual temperature ranges from 18 to 25°C, with rainfall distributed across two seasons: a wet season (November to April) and a dry season (May to October). Dominant native vegetation includes *Castanopsis argentea*, *Schima wallichii*, and *Altingia excelsa* (TNGunungCiremai, n.d.).

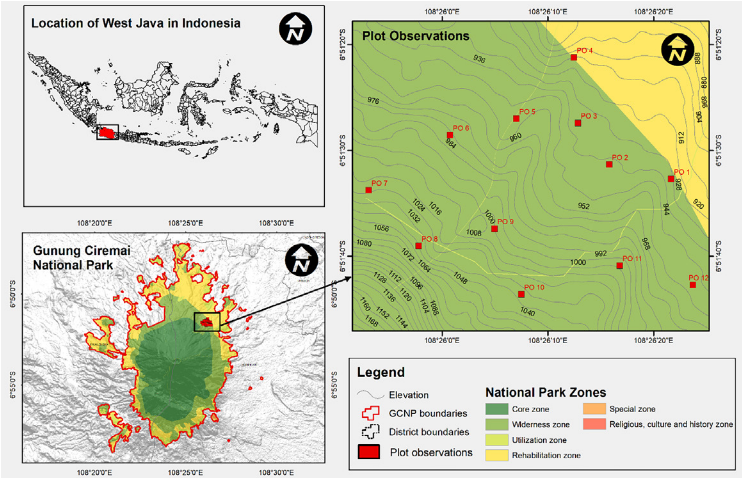

Figure 1. Map of research location in the wilderness zone of GCNP, West Java, Indonesia
Source: Tanah Air Indonesia (n.d.)

A maintained trail from the utilisation zone boundary provides access to the wilderness zone, potentially establishing invasion corridors through propagule dispersal and trail-edge disturbance (Barros *et al.*, 2025). *Calliandra calothyrsus* plantings in adjacent agroforestry systems (<500 m distant) provide propagule sources. Southwest-northeast winds during the wet season may facilitate seed dispersal into the wilderness interior.

Field sampling and data collection. To counteract the seasonal bias where dry-season sampling underestimates species richness by 30-40%, surveys were conducted during the wet season (November-December 2024), when germination peaks. Twelve observation plots (20 × 20 m, 0.48 ha total) were systematically established along transects perpendicular to main trails, stratified by elevation and trail distance (0-50 m, 51-100 m, > 100 m) (Fig. 1). Each plot used a nested subplot design: four 2 × 2 m subplots for saplings (1.5-3 m height, diameter < 10 cm), one 1 × 1 m subplot for seedlings (< 1.5 m height), and a whole 20 × 20 m plot for poles (diameter 10-20 cm) and trees (diameter > 20 cm). Environmental variables measured included elevation (GPS), slope (clinometer), canopy cover (spherical densimeter), and distance to trail. All fieldwork was conducted in compliance with ethical standards for biodiversity research and in accordance with the principles of the Convention on Biological Diversity (1992).

Data analysis. To comprehensively characterise species diversity and spatial structure of invasive alien plant communities, a set of complementary diversity and distribution indices was applied. Species diversity was quantified using the Shannon-Wiener index (H'; Eq. 1), where pi represents the proportion of individuals of species *i* relative to the total number of individuals (N); Simpson's dominance index (C; Eq. 2), calculated as the sum of squared species proportions (Σpi^2); Evenness (EH; Eq. 3), expressed as the ratio of H' to the natural logarithm of species richness ($\ln S$); species richness (R; Eq. 4), defined as the total number of species (S); and Margalef's index (Dmg; Eq. 5), which standardises species richness by sample size using the total number of individuals (N):

$$H' = -\Sigma pi \ln pi, \quad (1)$$

$$C = \Sigma pi^2, \quad (2)$$

$$EH = H'/\ln S, \quad (3)$$

$$R = S, \quad (4)$$

$$Dmg = (S - 1)/\ln N. \quad (5)$$

Spatial distribution patterns were assessed using Morisita's index ($I\delta$; Eq. 6), where q denotes the number of sampling units, x is the number of individuals per sampling unit, Σx^2 is the sum of squared individuals across all units, and N is the total number of individuals:

$$I\delta = q[\Sigma x^2 - N]/[N(N - 1)]. \quad (6)$$

Values of $I\delta < 1$, $= 1$, and > 1 indicate uniform, random, and clumped distributions, respectively. Importance values (IV = RF + RD + RDo) integrated relative frequency (RF), defined as the proportion of sampling units in which a species occurred relative to the total frequency of all species; density (RD), calculated as the number of individuals of a species divided by the total number of individuals across all species; and dominance (RDo), expressed as the contribution of a species to total community dominance, typically based on basal area or canopy cover relative to all species.

Cluster analysis. Hierarchical cluster analysis, using Ward's linkage with Bray-Curtis dissimilarity (Bray & Curtis, 1957; Borcard *et al.*, 2018), was used to reveal spatial invasion patterns in the tropical forest community (Pang *et al.*, 2023). Ward's method minimised within-cluster variation, thereby producing compact clusters suitable for identifying invasion gradients (Borcard *et al.*, 2018). The optimal number of clusters was determined based on dendrogram structure, ecological interpretability, and comparisons of within- and between-cluster dissimilarity. For each cluster, mean abundance, species richness, dominant species composition, and frequency were calculated. Analysis of Similarity (ANOSIM) with 999 permutations was applied to assess the statistical significance of cluster separation. Kruskal-Wallis tests followed by post hoc Dunn's tests were used to examine relationships between clusters and environmental factors, including elevation, slope, canopy cover, and distance from trails. Linear regression analysis was used to evaluate relationships between invasion parameters and distance from trails. All analyses were conducted using R version 4.3.0, with the vegan package for community ecology analyses and the cluster package for hierarchical clustering.

Results and Discussion

Composition and diversity of invasive alien plant species. A total of 18 IAPS from 9 families (421 individuals) were documented across 12 plots (Table 1). Poaceae was most diverse (4 species, 55.6%), followed by Fabaceae (2 species, 30.9%) and Asteraceae (3 species, 4.5%). *Panicum maximum* showed the highest importance value (106.54%), followed by *C. calothyrsus* (92.87%) and *Isachne globosa* (60.02%). These three species comprised 86.5% of the total IAPS abundance, indicating strong dominance.

Table 1. List of invasive alien plant species recorded in the wilderness zone of GCNP

No	Scientific name	Family	Growth stage	Origin	Reference
1	*Ageratina riparia*	Compositae	U	Mexico & the Caribbean (West Indies)	S. Setyawati *et al.* (2015), S.S. Tjitrosoedirdjo *et al.* (2016)

Table 1, Continued

No	Scientific name	Family	Growth stage	Origin	Reference
2	*Ageratum conyzoides*	Asteraceae	U	Tropical & South America	S. Setyawati *et al.* (2015)
3	*Bidens pilosa*	Asteraceae	U	Southern Africa	S. Setyawati *et al.* (2015), S.S. Tjitrosoedirdjo *et al.* (2016)
4	*Calliandra calothyrsus*	Fabaceae	Se., Sa., P, T	Central America & Mexico	S. Setyawati *et al.* (2015), S.S. Tjitrosoedirdjo *et al.* (2016)
5	*Centrosema pubescens*	Fabaceae	U	Central & South America	S. Setyawati *et al.* (2015)
6	*Chromolaena odorata*	Asteraceae	U	Central & South America	S. Setyawati *et al.* (2015), S.S. Tjitrosoedirdjo *et al.* (2016), Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P.16/MENLHK/SETJEN/OTL.0/1/2016 (2016)
7	*Clidemia hirta*	Melastomataceae	U	South America	S. Setyawati *et al.* (2015), S.S. Tjitrosoedirdjo *et al.* (2016), Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P.16/MENLHK/SETJEN/OTL.0/1/2016 (2016)
8	*Cyperus rotundus*	Cyperaceae	U	India / Africa	S. Setyawati *et al.* (2015)
9	*Isachne globosa*	Poaceae	U	South Asia	S. Setyawati *et al.* (2015)
10	*Lantana camara*	Verbenaceae	U	Central America	S. Setyawati *et al.* (2015), S.S. Tjitrosoedirdjo *et al.* (2016), Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P.16/MENLHK/SETJEN/OTL.0/1/2016 (2016)
11	*Melastoma malabathricum*	Melastomataceae	U	Asia	S. Setyawati *et al.* (2015), S.S. Tjitrosoedirdjo *et al.* (2016)
12	*Mikania micrantha*	Asteraceae	U	Central & South America	S. Setyawati *et al.* (2015), S.S. Tjitrosoedirdjo *et al.* (2016), Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P.16/MENLHK/SETJEN/OTL.0/1/2016 (2016)
13	*Mimosa pudica*	Fabaceae	U	Tropical & South America	S. Setyawati *et al.* (2015), S.S. Tjitrosoedirdjo *et al.* (2016), Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P.16/MENLHK/SETJEN/OTL.0/1/2016 (2016)

Table 1, Continued

No	Scientific name	Family	Growth stage	Origin	Reference
14	*Piper aduncum*	Piperaceae	U, Se., Sa.	South America	S. Setyawati *et al.* (2015), S.S. Tjitrosoedirdjo *et al.* (2016), Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P.16/MENLHK/SETJEN/OTL.0/1/2016 (2016)
15	*Solanum torvum*	Solanaceae	U	Antilles / Caribbean	S. Setyawati *et al.* (2015)
16	*Stachytarpheta jamaicensis*	Verbenaceae	U	Tropical America	S. Setyawati *et al.* (2015), S.S. Tjitrosoedirdjo *et al.* (2016)
17	*Synedrella nodiflora*	Asteraceae	U	Central & South America	S. Setyawati *et al.* (2015)
18	*Panicum maximum*	Poaceae	U	Tropical Africa	S. Setyawati *et al.* (2015), Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P.16/MENLHK/SETJEN/OTL.0/1/2016 (2016)

Note: U – Understorey; Se – Seedling; Sa. – Sapling; P – Pole; T – Tree
Source: developed by the authors

Growth stage analysis revealed the following distribution: seedlings (162 individuals, 38.5%), saplings (115, 27.3%), poles (92, 21.9%), and trees (52, 12.4%). *C. calothyrsus* demonstrated successful reproduction across all stages (seedlings 36, saplings 41, poles 28, trees 25), indicating established reproducing populations. Most grass species occurred primarily as seedlings and saplings, suggesting recent colonisation or recruitment limitation. *C. calothyrsus* establishment across all growth stages has critical management implications. Mountain invasions are anticipated to increase as thermal barriers decrease. F. de Vries *et al.* (2023) investigated upward range expansion specifically in tropical mountain systems. They found that invasive plant species exhibited significantly faster altitudinal migration rates (15-30 m per decade) than native species (5-10 m per decade), creating novel community structures at high altitudes. Their study demonstrated that invasive species often possess broader thermal tolerances and greater phenotypic plasticity, enabling them to rapid exploit new, suitable habitats. I. Nasihin *et al.* (2024) applied species distribution modelling to predict the range dynamics of *C. calothyrsus* in the GCNP. They projected continued upward expansion, with a potential increase in suitable habitat of 26.93%. The current findings of established reproductive populations at all growth stages (seedlings to trees) at 900-1,400 m elevation confirm that *C. calothyrsus* has successfully breached historical thermal barriers and established self-sustaining populations in the GCNP mountain wilderness zone, validating the climate-invasion predictions from this study. The findings reveal internal seed sources within the wilderness zone, potentially accelerating invasion through local dispersal. B. Zhang *et al.* (2023) conducted a comparative analysis of dispersal rates between invasive and native plant species across different life forms and ecological contexts. Their study demonstrated that anthropogenic dispersal vectors (human foot traffic, equipment transportation, vehicle movement) facilitate the spread of invasive species at rates 50-100 times faster than natural dispersal mechanisms (wind, animal vectors, gravity). Specifically for invasive herbaceous and woody plants in protected areas, B. Zhang *et al.* documented that trails and recreational infrastructure create dispersal pathways that enable rapid range expansion, with the invasion front advancing 10-50 meters per year along the corridor compared to 1-5 meters per year in undisturbed areas. Their findings emphasise that once invasive species establish a propagule source near a trail, they can rapidly colonise surrounding areas through anthropogenic and natural dispersal, creating accelerating invasion dynamics. The Documentation of a reproductive population of *C. calothyrsus* in Cluster 2 plots (adjacent to the trail) serving as a seed source for Cluster 1 plots (at an intermediate distance) confirms B. Zhang's *et al.* corridor-facilitated invasion model. The presence of an established internal seed source within the wilderness zone, coupled with persistent visitor traffic on the trail, suggests that invasion expansion will continue and potentially increase without targeted interventions to remove the propagule source and disrupt anthropogenic dispersal pathways. Population viability analysis would determine if populations are self-sustaining (requiring containment strategies) or propagule-limited (enabling local eradication through barriers and source control).

Diversity indices showed moderate to high plot diversity (Table 2, 3). The Shannon-Wiener index ranged from 0.82 to 1.98 (mean 1.42 ± 0.35), indicating spatial heterogeneity. Simpson's dominance (0.23-0.67, mean 0.41 ± 0.13) indicated 3-4 species typically dominated each plot. Evenness values (0.51-0.91, mean 0.73 ± 0.12) showed relatively balanced distributions, though some plots displayed single-species dominance. Species richness ranged from 2 to 6 per plot (mean 4.1 ± 1.3).

Table 2. Diversity indices and spatial distribution patterns of invasive alien plant species in the understorey (ground vegetation) of the wilderness zone of GCNP

Species	Density (ind/m²)	Frequency	H'	C	Distribution (Morisita)
Panicum maximum	45.3	0.83	0.37	0.07	Clumped (1.85)
Isachne globosa	38.7	0.75	0.36	0.04	Clumped (1.92)
Chromolaena odorata	28.5	0.67	0.28	0.05	Clumped (1.65)
Ageratum conyzoides	22.1	0.58	0.24	0.04	Clumped (1.58)
Lantana camara	12.4	0.42	0.12	0.01	Uniform (0.85)
Other species (12 spp.)	53	-	-	-	Variable

Source: developed by the authors

Table 3. Diversity indices and spatial distribution patterns of invasive alien plant species across woody growth stages in the wilderness zone of GCNP

Growth Stage	No. Spp.	Dominant Species	H'	C	Distribution
Seedling (<1.5 m)	2	*C. calothyrsus*	0.23	0.49	Clumped (1.78)
Sapling (1.5-5 cm DBH)	2	*C. calothyrsus*	0.27	0.4	Clumped (1.68)
Pole (5-20 cm DBH)	1	*C. calothyrsus*	0.28	0.46	Clumped (1.55)
Tree (>20 cm DBH)	1	*C. calothyrsus*	0	1	Uniform (0.92)

Note: DBH – diameter at breast height
Source: developed by the authors

Spatial distribution patterns (Morisita's index) demonstrated predominantly clumped distributions: *P. maximum* ($I\delta = 1.84$), *I. globosa* ($I\delta = 2.13$), and *C. calothyrsus* ($I\delta = 3.47$) all showed significant aggregation ($p < 0.05$). Only *Lantana camara* ($I\delta = 1.12$) approached random distribution. Clumped patterns likely reflect vegetative reproduction, limited seed dispersal, and microhabitat preferences, with important implications for targeted control efforts. Wet-season sampling addresses significant temporal bias in Indonesian invasion studies. M. Belayhun *et al.* (2024) conducted comparative wet- and dry-season surveys in Ethiopian protected areas. They documented that wet-season surveys detected 30-40% more invasive species than dry-season inventories, particularly annual forbs and recent colonisers that complete their life cycles during high-rainfall periods. Their findings emphasized the importance of seasonal timing in invasion assessments, as many herbaceous invasive species remain dormant or inconspicuous during dry periods. Wet-season sampling methodology aligns with M. Belayhun's *et al.* recommendations and successfully documented species such as *M. pudica* and grass seedling cohorts during peak rainfall, providing baseline data on species that would likely be overlooked in dry-season inventories. This temporal approach has important implications for control timing, as interventions targeting reproductive stages during wet seasons may be more effective than those targeting dry-season stages. Documentation of *M. pudica* and grass seedling cohorts during high rainfall provides baseline data on species that may be overlooked in dry-season inventories, with implications for control timing.

Spatial invasion patterns and corridor-based invasion dynamics. Hierarchical clustering identified three statistically distinct groups of invasion intensity (Fig. 2; ANOSIM $R = 0.68$, $p = 0.001$), aligning with patterns observed in other tropical forests (Pang *et al.*, 2023). The stated hypothesis was supported by the results, as invasion intensity significantly declined with increasing distance from trails ($R^2 = 0.78$, $p < 0.001$), and hierarchical cluster analysis identified three distinct invasion intensity zones. Between-cluster dissimilarity (mean 0.72 ± 0.18) significantly exceeded within-cluster dissimilarity (Cluster 1: 0.52 ± 0.21; Cluster 2: 0.65 ± 0.31; Kruskal-Wallis $\chi^2 = 18.3$, $p < 0.001$), confirming compositionally distinct zones.

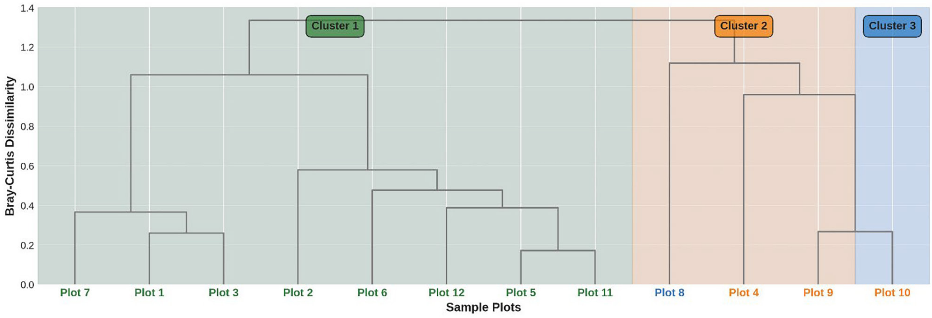

Figure 2. Hierarchical cluster analysis of invasive species composition

Source: developed by the authors

This work provides the first comprehensive spatial analysis of invasive plants within an Indonesian wilderness zone. The hierarchical cluster analysis reveals highly spatially stratified invasion intensity, with three zones differing in species composition, abundance, and functional groups. This spatial heterogeneity has significant management implications: spatial targeting based on invasion intensity mapping can enhance resource allocation, whereas uniform strategies may be ineffective. P. Courtois *et al.* (2023) developed spatially explicit management models for protected areas and demonstrated that stratified management approaches based on invasion intensity zones achieved 3-5 times greater cost-effectiveness than uniform interventions. Their work showed that concentrating resources on high-invasion hotspots, while maintaining surveillance in moderate-invasion zones, prevented both species spread and resource waste. Hierarchical cluster analysis provides precisely this type of spatial stratification, identifying three distinct management zones that enable targeted resource allocation. Compared with P. Courtois's *et al.* framework, Cluster 2 (high invasion, 25% of plots) represents priority intervention zones where immediate control efforts are expected to yield the greatest return. In contrast, Cluster 1 (moderate invasion, 67% of plots) requires sustained monitoring rather than intensive intervention.

Cluster 1: Moderate invasion – grass-dominated assemblages. Eight plots (67%: Plots 1, 2, 3, 5, 6, 7, 11, 12) showed intermediate invasion intensity (37.5 ± 11.5 ind/plot) and the highest diversity (4.6 ± 1.1 species/plot; Figs. 3-5). *P. maximum* (136 individuals, 45.3%) and *I. globosa* (90, 30.0%) predominated, with *C. calothyrsus* contributing 13.0% (39 individuals). Co-dominance without competitive exclusion suggests an early to intermediate stage of invasion. Plots occurred at intermediate trail distances (mean 85 ± 25 m) with moderate canopy openness (45 ± 12%).

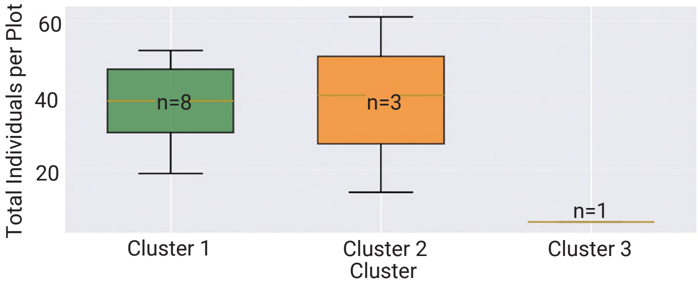

Figure 3. Total abundance

Source: developed by the authors

Figure 4. Species richness

Source: developed by the authors

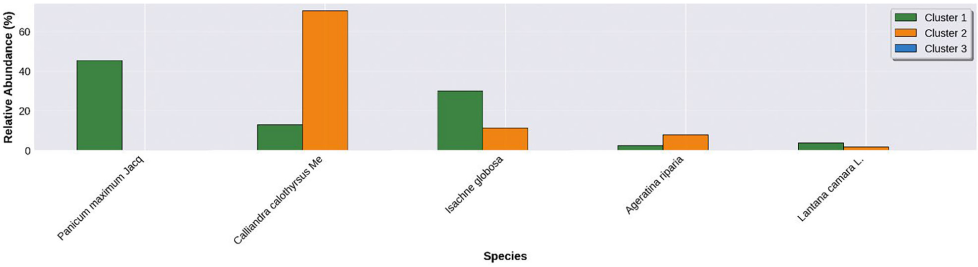

Figure 5. Composition of top 5 dominant species

Source: developed by the authors

Compositional features suggest an intermediate invasion stage with implications for succession. The shift from grass-dominated to woody-dominated assemblages may represent a successional sequence. B.A. Bradley *et al.* (2024) investigated invasion succession dynamics in disturbed forest ecosystems and found that shade-intolerant grasses typically colonise immediately following disturbance events, creating dense herbaceous layers. Their research demonstrated that these early-stage grass invasions can facilitate subsequent woody invasions by modifying microclimatic conditions and soil properties. The observations of *C. calothyrsus* seedlings co-occurring beneath *P. maximum* and *I. globosa* grass cover in Cluster 1 plots support this facilitation hypothesis, suggesting that current grass-dominated plots (Cluster 1) may transition to woody-dominated assemblages (Cluster 2) without intervention. Management implications depend on invasion pathways. If grass-to-woody succession is confirmed, early grass control may prevent woody invasion. However, if functional groups invade independently along different gradients, simultaneous management is required. M. Wang *et al.* (2024) demonstrated that functional traits and phylogeny jointly regulate species' spatial distribution patterns, with environmental filtering and dispersal limitation as the primary drivers of community assembly. Their application of partial constrained correspondence analysis successfully partitioned variance among these mechanisms, revealing that environmental filtering accounted for 45-60% of compositional variation in tropical forests, while dispersal limitation accounted for 25-35%.

Cluster 2: High invasion – *Calliandra*-dominated woody invasion. Three plots (25%: Plots 4, 9, 10) exhibited the highest invasion intensity, dominated by *C. calothyrsus*. Mean abundance was 38.3 ± 23.5 ind/plot (range 14-61), with high variability reflecting different successional stages. Mean species richness (3.7 ± 1.5 species/plot) was significantly lower than Cluster 1 ($p = 0.04$), indicating competitive exclusion. *C. calothyrsus* comprised 81 individuals (70.4%) with 100% frequency, demonstrating complete dominance. Secondary species included *I. globosa* (13, 11.3%), Ageratina riparia (9, 7.8%), and *Piper aduncum* (4, 3.5%). Species composition indicates advanced invasion, as *C. calothyrsus* has established reproductive populations across growth stages and begun excluding other species. Plots occurred nearest trails (mean 45 ± 15 m) with the highest canopy openness (62 ± 18%; significantly greater than Cluster 1, $p = 0.02$).

C. calothyrsus dominated plots near trails empirically validate corridor-based invasion models proposed for protected areas globally. P. Szilassi *et al.* (2021) analysed country-scale spatial data. They found that road networks, railways, watercourses, and ecological corridors provide interconnected pathways for biological invasion, with protected areas showing edge effects extending up to 200 meters from infrastructure. Quantitative results of current study strongly support these corridor-invasion models: *C. calothyrsus* dominance (70%) occurs exclusively within 60 meters of trails, declining to zero beyond 150 meters ($R^2 = 0.78$, $p < 0.001$). This represents one of the first empirical tests of corridor-invasion hypotheses in tropical montane wilderness zones, extending P. Szilassi's frameworks to Southeast Asian protected areas. The transparent invasion Gradient (70% dominance near trails declining to 0% at > 150 m) demonstrates that trails are active invasion channels concentrating disturbance and propagule pressure. A. Barros *et al.* (2025) investigated mechanisms of trail-mediated invasion in protected forests. They identified four primary pathways: (1) seed transport via footwear, equipment, and vehicles, (2) canopy opening during trail construction and maintenance creating light gaps, (3) altered microclimate along trail edges with increased temperature and reduced humidity, favouring invasive species, and (4) soil disturbance, reducing native plant competitiveness while creating establishment opportunities for ruderals. Their experimental tracking demonstrated that a single hiker can transport 100-300 seeds per kilometre, with propagule loads increasing substantially in invaded areas. The field observations of current study confirm these mechanisms operating in GCNP wilderness zones: trail-adjacent plots (Cluster 2) show evidence of regular disturbance (compacted soils, canopy gaps), explaining the 70% *C. calothyrsus* dominance, while plots beyond direct trail influence (Cluster 1, 3) retain greater native plant cover and lower invasion intensity. The quantitative relationship ($R^2 = 0.78$) suggests even modest trail distance increases (50-100 m) could substantially reduce invasion risk. K. Utkhamthiang *et al.* (2025) explained that trails function as invasion corridors in protected areas, with recreational activities facilitating the dispersal of invasive species through contaminated footwear and equipment. Their documentation of trail-mediated invasion patterns in Doi Chiang Dao Biosphere Reserve confirmed that spatial management strategies controlling propagule sources near trails can effectively reduce invasion intensity.

Cluster 3: Low invasion – peripheral resistance zone. Plot 8 (8%) had minimal invasion intensity, characterised by a unique composition: *Melastoma malabathricum* (2 individuals, 33.3%) and *Mimosa pudica* (4 individuals, 66.7%), both of which are rare elsewhere. The location, at maximum trail distance (> 150 m) with dense canopy cover (75%) and minimal disturbance, likely explains the low invasion and the unique assemblage. This plot represents either an early invasion front with low propagule pressure or a site with environmental resistance. This peripheral plot demonstrates invasion resistance achievable with minimal disruption. Linear regression showed *C. calothyrsus* abundance decreased significantly with trail distance ($R^2 = 0.78$, $p < 0.001$), while native plant cover increased ($R^2 = 0.65$, $p = 0.002$). All Cluster 2 plots (high invasion) occurred within 60 m of trails, while Cluster 3 (minimal invasion) was > 150 m from the nearest trail. This pattern supports corridor-based invasion where trails are primary propagule vectors and invasion intensity declines with distance from disturbance sources. Compositional turnover between clusters, characterised by high between-cluster dissimilarity (0.72), coupled with moderate heterogeneity within Cluster 1 (0.52), suggests ongoing invasion dynamics with spatial variability in community assembly. Three distinct zones provide a spatial framework for prioritising management, with Cluster 2 requiring immediate attention to prevent the further establishment and seed production of *C. calothyrsus*.

The findings of current study demonstrate the effectiveness of integrating diversity indices with multivariate spatial analysis, a currently uncommon approach in Indonesian invasion ecology. Cluster analysis revealed that *C. calothyrsus* follows a spatially explicit invasion pathway, with initial establishment in trail-adjacent plots (Cluster 2) followed by potential spread to intermediate grass-dominated plots (Cluster 1). Traditional diversity indices alone indicated high importance values throughout the study area but failed to reveal this critical spatial structure governing invasion dynamics. These results contribute to growing evidence that protected areas face mounting threats from multiple interacting stressors. L. Carneiro *et al.* (2024) documented accelerating invasion rates across global protected area networks, attributing these increases to synergistic effects among climate change, habitat fragmentation, and visitor pressure. Their analysis demonstrated that protected areas with high visitation rates experience 2-3 times greater invasion rates than strictly protected zones with minimal access. The findings of current study support this pattern, as GCNP's recreational trails create invasion corridors penetrating the wilderness zone. B. Gallardo & L. Capdevila-Argüelles (2024) specifically examined the effects of climate change on non-native species in protected areas. They found that warming temperatures enable invasive species to colonise higher elevations previously considered thermal refugia, with montane protected areas particularly vulnerable. This climate-invasion interaction may explain *C. calothyrsus* successful establishment at 2,400-2,800 m elevation in GCNP, elevations historically considered beyond its range. The economic dimensions of biological invasions in protected areas warrant consideration. C. Diagne *et al.* (2021) quantified the global economic costs of invasive alien species using the InvaCost database. They showed that damage costs far exceed management expenditures, and that a delayed response leads to rapidly escalating costs as the invaded area expands. Similarly, R.N. Cuthbert *et al.* (2021) further examined the economic effectiveness of management timing. They showed that early intervention and prevention yield significantly higher economic returns than post-establishment control, as costs increase disproportionately as the invasion spreads. Identification of three small, highly invasive plots (Cluster 2) as an immediate management priority is consistent with this economic framework, as containment at this stage requires relatively modest investment, whereas allowing spread to 67% of plots (Cluster 1) would require significantly greater future expenditure.

Management implications and conservation priorities. Cluster analysis provides a spatial framework for prioritising interventions in wilderness zones. A three-tiered management approach is recommended:

- Priority 1. Immediate control (Cluster 2): Focus resources on three *C. calothyrsus* dominated plots (4, 9, 10) nearest trails. Manual removal of all individuals before September-October flowering should occur annually for ⩾ 5 years to exhaust soil seed banks (typical longevity 3-7 years). These plots serve as seed sources; their containment is critical. Removed biomass should be burned on-site or transported off-mountain to prevent vegetative regeneration. Early intervention in limited high-invasion zones is substantially more cost-effective than a delayed response, as demonstrated by C. Diagne *et al.* (2021), who quantified the global economic costs of invasive alien species using the InvaCost database and showed that damage costs escalate rapidly when management is postponed, far exceeding early control expenditures. R.N. Cuthbert *et al.* (2021**)** further found that prevention and early-stage management provide disproportionately higher economic benefits than post-establishment control, because costs increase sharply once invasions spread spatially.

◆ Priority 2. Sustained monitoring (Cluster 1): Implement biannual grass cutting (pre-flowering April and September) in eight mixed-composition plots to prevent *P. maximum* and *I. globosa* seed production. Monitor quarterly for *C. calothyrsus* seedlings and remove them immediately. Native plant restoration through enrichment planting may accelerate canopy closure, reducing light for shade-intolerant grasses while promoting functional diversity, enhancing invasion resistance. A.R. Ernst *et al.* (2025) demonstrated that strategic native tree planting in invaded grasslands reduced invasive grass cover by 65-80% within 3-5 years through light competition, with native seedling survival exceeding 75% when planted during optimal seasons. I. Kim *et al.* (2025) investigated relationships between native species diversity and invasion resistance, finding that plots with higher native functional diversity (particularly canopy tree species) had 40-60% lower invasive plant richness than species-poor plots. Their work emphasised that native community restoration provides long-term invasion resistance superior to repeated invasive removal alone. L. Petri & I. Ibáñez (2025) examined post-removal recovery dynamics. They documented that native plant recovery success depended critically on native community features present at the time of invasive removal, with sites retaining diverse native propagule banks showing rapid natural regeneration. Applying these findings to GCNP, enrichment planting of native canopy species in Cluster 1 plots could reduce light availability for *P. maximum* and *I. globosa*, while simultaneously reducing establishment opportunities for *C. calothyrsus* seedlings, providing integrated management of both grass and woody invaders.

◆ Priority 3. Protection (Cluster 3): Maintain low-invasion peripheral plot (8) as reference site through strict access restrictions and quarterly monitoring. This plot demonstrates invasion resistance with minimal disturbance. Remove any detected IAPS immediately. Long-term monitoring will reveal whether this plot remains resistant or eventually succumbs to the pressure of propagules.

Spatial management strategy. Establish 50-m buffer zones around Cluster 2 plots for intensive quarterly monitoring. Create physical barriers to limit seed dispersal along prevailing wind directions (southwest-northeast monsoon) if feasible. Restrict trail maintenance during *C. calothyrsus* seed dispersal (October-December) to prevent propagule transport. Education programs on boot-washing and equipment cleaning could substantially reduce accidental propagule introduction. P.E. Hulme (2024) analysed international tourists as biosecurity pathways into national parks and found that visitors inadvertently transport invasive propagules through contaminated footwear, clothing, and equipment. P.E. Hulme's research demonstrated that simple biosecurity interventions – including boot-washing stations, equipment cleaning guidelines, and educational signage – reduced propagule transport by 60-85% when compliance exceeded 70%. Implementation costs were modest (<$5,000 USD per facility), and ongoing maintenance requirements were minimal. For GCNP, installing boot-cleaning stations at the wilderness zone trailhead, combined with interpretive signage explaining invasion threats, could significantly reduce propagule introduction rates. Trail infrastructure design also influences invasion risk. A. Barros *et al.* (2025) provided design guidelines for minimising edge effects while maintaining visitor access, recommending: (1) minimising trail width to reduce disturbed area, (2) avoiding trail routing through intact forest that creates new edges, (3) utilising existing degraded corridors, when possible, (4) implementing drainage management preventing water-facilitated seed dispersal, and

(5) conducting regular trail maintenance outside peak seed dispersal periods. These design principles, if applied to GCNP trail management, could reduce corridor-mediated invasion while preserving recreational and ranger access to wilderness zones.

The findings of this study highlight the complexity of invasive plant distribution in the wilderness zone of Gunung Ciremai National Park, emphasising the role of spatial patterns in invasion intensity. The identification of three distinct zones of invasion intensity provides critical insights into the dynamics of plant colonisation and dispersal. The use of multivariate analyses and seasonal sampling methods has allowed for a comprehensive understanding of the invasion process, addressing several gaps in current research.

Conclusions

This study presents the first quantitative spatial analysis of invasive alien plants in an Indonesian wilderness zone, identifying three statistically distinct zones of invasion intensity that contrast with uniform invasion assumptions. Clear spatial structure (between-cluster dissimilarity 0.72), strong distance-decay with trails ($R^2 = 0.78$), and identification of hotspots dominated by *C. calothyrsus* (70% in Cluster 2) demonstrate that sophisticated multivariate methods detect spatial patterns invisible to traditional diversity indices. The findings validate corridor-based invasion models for tropical montane protected areas and establish a replicable methodology for other understudied wilderness zones. Integration of wet-season sampling, hierarchical cluster analysis, and growth-stage assessment addresses multiple research gaps: the lack of fine-scale spatial data for tropical protected areas, temporal bias toward dry seasons, the absence of multivariate approaches in Indonesian invasion ecology, and insufficient understanding of infrastructure impacts. These methodological advances, combined with evidence that anthropogenic dispersal exceeds natural colonisation, underscore the urgency of proactive management.

The three-tier management framework, derived from cluster analysis, provides actionable, spatially explicit priorities: immediate control in high-invasion zones, sustained monitoring in moderate zones, and protection of peripheral areas. Implementation could prevent further degradation of the wilderness zone and serve as a model for other Indonesian national parks facing similar challenges. As Southeast Asian biodiversity faces mounting threats from habitat loss, biological invasions, and climate change, such evidence-based approaches become increasingly critical. Spatial targeting of management resources is both ecologically and economically justified, as the financial benefits of early action substantially exceed the costs of a delayed response. The prospects for further research include expanding the analysis to other protected areas in Indonesia and Southeast Asia to compare the effectiveness of invasion management strategies. Additionally, studying the impact of climate change on the spread of invasive species will allow for more accurate predictions of future ecological threats.

Acknowledgements

The authors express their appreciation to Universitas Kuningan's Institute for Research and Community Service (LPPM) for their assistance and support.

Funding

Research funding assistance was obtained from Universitas Kuningan's Institute for Research and Community Service (LPPM)

Conflict of Interest

None.

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Осередки інвазії у зонах дикої природи тропічних національних парків

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Анотація. Чужорідні інвазійні рослинні види все більше загрожують цілісності лісових екосистем у природоохоронних територіях, особливо в малодосліджених зонах дикої природи тропічних національних парків. Метою цього дослідження було оцінити просторовий розподіл та інтенсивність інвазії чужорідних рослинних видів у зоні дикої природи національного парку Гунунг Чиремай, Західна Ява, Індонезія. Під час дощового сезону було проведено всебічне географічне дослідження, використовуючи дванадцять систематично встановлених ділянок (20 × 20 м) з підділянками, що представляють різні стадії росту. Було зафіксовано 18 видів інвазивних чужорідних рослин, що належать до дев'яти родин. Ієрархічний кластерний аналіз виявив три статистично різні зони інтенсивності інвазії: помірно заражену зону (67 % ділянок), доміновану *Panicum maximum* та *Isachne globosa*; сильно заражену зону (25 % ділянок), що характеризується сильним домінуванням деревного бобового виду *Calliandra calothyrsus*; та зону з низьким рівнем інвазії (8 % ділянок), з мінімальним заселенням. Відмінність між кластерами за Брее-Кертісом (0,72 ± 0,18) перевищила внутрішньокластерні значення (0,52-0,65), що свідчить про виражену композиційну диференціацію. Патерн інвазії, заснований на коридорах, підтвердився значним зниженням інтенсивності інвазії з відстанню від стежок ($R^2 = 0{,}78$, $p < 0{,}001$). Дослідження стало першим кількісним просторовим оцінюванням розподілу інвазивних рослин у зонах дикої природи індонезійських природоохоронних територій та продемонструвало цінність багатовимірних аналізів для виявлення осередків інвазії та формування цільових стратегій управління

Ключові слова: біологічна інвазія; дисимілярність Брее-Кертіса; кластерний аналіз; природоохоронні території; просторові патерни

Received: 28.07.2025; Revised: 24.10.2025; Accepted: 27.11.2025

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Journal homepage: https://forestscience.com.ua/en
Ukrainian Journal of Forest and Wood Science, 16(4)

UDC 581.543:582.711.714
DOI: 10.31548/forest/4.2025.89

Phenological growth stages of sorboid group within *Malinae* (*Rosaceae*) according to the BBCH scale

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Suggested Citation:
Mezhenskyj, V., Mezhenska, L., Marchuk, Yu., Mazur, B., Havryliuk, O., & Kovalchuk, S. (2025). Phenological growth stages of sorboid group within *Malinae* (*Rosaceae*) according to the BBCH scale. *Ukrainian Journal of Forest and Wood Science*, 16(4), 89-107. doi: 10.31548/forest/4.2025.89.

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Abstract. The development of a unified system for monitoring the developmental stages of sorboid plants within the subtribe *Malinae* holds significant economic and ecological importance. The study aimed to develop a comprehensive phenological system for sorboid plants based on the extended BBCH scale. The research was conducted during 2024-2025 at the collection sites of the National University of Life and Environmental Sciences of Ukraine and covered 49 species-level taxa representing the genera *Aria*, *Aronia*, *Cormus*, *Hedlundia*, *Micromeles*, and *Sorbus*, as well as the nothogenera ×*Amelasorbus*, ×*Arsorbus*, ×*Pyraria*, ×*Sorbaronia*, ×*Sorbocotoneaster*, and ×*Sorbopyrus*. The methodology involved regular field observations of individual plants, with developmental stages documented through systematic in situ photography throughout the growing season. The development of the extended scale was based on the principles of the decimal BBCH coding system and incorporated refined morphological descriptors for both vegetative and reproductive organs. To account for secondary and tertiary growth cycles observed under recent climatic shifts, a dual-indexing system was implemented to document successive proleptic shoots. The proposed scale consists of eight principal growth stages, substantially adapted to reflect the specific biological traits of sorboid plants. Key modifications include improved descriptors for bud and inflorescence emergence, a numerical system for recording multiple growth flushes (stages 31-39), and a redefinition of late-season stages to emphasise structural and physiological markers, such as leaf fall and winter dormancy, rather than transient optical traits. This standardised coding system provides high precision for bioclimatic monitoring, winter hardiness assessment, and the international exchange of scientific data on sorboid genetic resources. The results of the study can be applied in practice for monitoring the development of sorboid plants in forestry, horticulture, and biodiversity conservation

Keywords: *Aria*; *Aronia*; Cormus; *Hedlundia*; *Micromeles*; *Sorbus*; intergeneric hybrids; nothotaxa; phenology

Introduction

The subtribe *Malinae* (*Rosaceae*) comprises plants of considerable economic and ecological importance. While widely recognised for including globally important fruit crops, this group also occupies a prominent position in forestry and wood-processing industries. Many species of *Malinae* are integral components of natural forest communities, where they play a vital role in supporting biodiversity as a primary food source for forest avifauna and wildlife. From a silvicultural perspective, certain members of this subtribe are valued for the technical properties of their timber. As such, these plants contribute to both the ecological stability and the economic potential of forest stands, representing an important element in sustainable forest management. They are also valuable as fruit, ornamental, and medicinal plants.

Within the *Malinae*, a distinct group of sorboid plants is identified by their compound infructescences, bearing multiple fruits. Historically, these were unified within a broad circumscription of the genus Sorbus sensu Hedlund. Throughout the 20th century, taxonomic opinions diverged from this broad classification of *Sorbus sensu* lato to its segregation into the distinct genera *Aria, Chamaemespilus, Cormus, Micromeles, Sorbus* sensu stricto, and *Torminalis*, with *Aronia* also recognised as a separate genus (Fay & Rich, 2022a). The validity of such a division has been further substantiated by molecular phylogenetic studies. Species of these genera interbreed with one another, forming numerous hybridogenous taxa, for which new generic and nothogeneric names have been proposed. Nevertheless, M.F. Fay & T.C.G. Rich (2022b) continued to adhere to traditional concepts of *Sorbus* sensu lato.

Such divergent classification systems are often impractical for professionals working in botany, forestry, horticulture, ornamental gardening, and nature conservation. Addressing this, S.L. Mosyakin *et al.* (2022) proposed the conservation of the name *Aria* against *Chamaemespilus* and *Torminalis*. This proposal, based on the close taxonomic affinity of these genera, was subsequently accepted by the General Committee (Wilson, 2024). S.L. Mosyakin *et al.* (2025) indicated that, as a result, only four generic names: *Sorbus* sensu stricto, *Cormus, Aria*, and *Hedlundia* are retained for the sorboid species occurring in Western Eurasia, while most other names of hybridogenous genera and nothogenera have become unnecessary. A minor addition is the nothogenus ×*Arsorbus* (= *Aria* × *Sorbus*), which Z.-H. Feng *et al.* (2024) proposed to accommodate a single nothospecies. Furthermore, J.-H. Ma *et al.* (2023) and J. Hu *et al.* (2025) have demonstrated that the establishment of new genera for East Asian sorboid species is not molecularly substantiated. J.-H. Ma *et al.* (2003) employed plastome phylogenomics to resolve the relationships among East Asian sorboid species. Their findings confirmed that *Micromeles* is a monophyletic group, sharing a stable evolutionary history with *Aria, Chamaemespilus, Cormus, Sorbus* s.s., and *Torminalis*. By establishing the monophyly of these six traditional lineages, they provided the molecular evidence needed to show that creating additional genera for East Asian taxa would be redundant, as these species fit clearly into the existing framework. J. Hu *et al.* (2025) expanded upon this by conducting a broader molecular phylogenetic analysis, focusing on the taxonomic implications for the *Maleae* tribe. They reinforced the monophyletic status of the aforementioned core genera. Their work highlights that since the current six-group structure is robustly supported, any further splitting of East Asian sorboids lacks phylogenetic justification.

Regarding the flora of Ukraine, M.M. Fedoronchuk (2022) noted that eight sorboid species occur naturally, one of which is of conservation concern. Beyond native taxa, a significant number of sorboid plants have been introduced and cultivated in the country. Phenology, the study of recurring biological events and their timing in relation to biotic and abiotic forces, serves as a fundamental discipline for understanding ecosystem dynamics. In the contemporary context of global environmental change, D. Papagiannopoulou & T. Tsitsoni (2022) emphasised that phenological observations provide highly sensitive indicators of climate-driven shifts within biota. Beyond its role in bioclimatic monitoring, phenology remains indispensable for assessing ecological synchrony, predicting agricultural cycles, and managing biodiversity conservation. By integrating long-term observational data with predictive modelling, this field offers essential insights into the adaptive strategies of species and the functional stability of diverse habitats.

The BBCH (Biologische Bundesanstalt, Bundessortenamt, and the Chemische Industrie) scale was established to provide a standardised framework for phenological observations, offering a detailed description of plant developmental stages through a consistent coding system. The system was developed to encompass a diverse range of taxa, assigning identical codes to analogous growth stages across different species. This framework is structured into principal and secondary growth stages, ensuring high precision in bioclimatic monitoring and the international exchange of scientific data. While initially designed for major arable crops, the scale has since been extensively adapted for various horticultural and silvicultural species, including fruit crops and forest trees. These adapted scales already encompass a significant number of economically important plants, and the list of taxa for which BBCH-compliant descriptions are available continues to expand annually.

This study aimed to establish a standardised phenological framework for sorboid plants by developing an extended BBCH scale. In doing so, this study addresses a significant gap in current botanical, horticultural, and silvicultural knowledge, providing a unified tool for the monitoring of these diverse taxa.

Materials and Methods

The study was conducted at the collection orchard of the Educational, Research and Productive Laboratory of Genetic Resources, Introduction and Breeding of Rare Fruit and Ornamental Plants, within the Prof. V. L. Symyrenko Department of Horticulture at the National University of Life and Environmental Sciences of Ukraine (NULESU). The site was located in the village of Pshenychne, Bila Tserkva district, Kyiv region (50°05’17” N, 30°13’04.0” E). This region is situated within the Forest-Steppe natural zone. According to the Köppen climate classification scheme, the area is characterised by a typical warm-summer humid continental climate (Dfb). The basis for this research was the extensive collection of sorboid plants maintained by NULESU, which represents one of the most comprehensive genetic repositories of this group in the region (Mezhenska *et al.*, 2018; Mezhenskyj, 2019). This collection served as the primary resource for selecting the 49 species-level taxa included in the observations. Phenological monitoring was conducted during 2024-2025. Visual documentation of the phenological progression was performed by capturing sequential images of each growth stage *in situ* within the orchard to ensure precise identification and standardisation. All research activities were conducted in accordance with the Convention on Biological Diversity (CBD, 1992) and relevant Ukrainian legislation. The plant material was sourced exclusively from the ex situ collection maintained at NULESU, and no sampling from natural populations was performed. Phenological observations were non-destructive and did not affect plant welfare.

The taxonomic selection for this study was based on modern generic concepts proposed for sorboid plants. Firstly, segregated systems substantiated by molecular phylogenetic evidence were adopted, as established by C.S. Campbell *et al.* (2007) and J.H. Sun *et al.* (2018). This approach aligned the sample selection with current evolutionary data, ensuring that the diversity of the *Malinae* was represented through distinct generic entities rather than a broad traditional circumscription. Furthermore, the taxonomic framework of this study incorporated the proposal by A.N. Sennikov & A. Kurtto (2017) regarding the establishment of the hybridogenous genera for sorboids. The subsequent nomenclatural refinements suggested by S.L. Mosyakin *et al.* (2022; 2025) were also followed, which simplify the system of sorboid genera in Europe through the conservation of the name *Aria*. This also included the recognition of the established nothogenus ×*Arsorbus*, as proposed by Z.-H. Feng *et al.* (2024). The systematic treatment of Eurasian taxa belonging to *Micromeles,* followed by L.O. Mezhenska *et al.* (2018). This classification has gained robust support from the molecular phylogenetic studies of J.-H. Ma *et al.* (2023) and J. Hu *et al.* (2025), which demonstrated that the alternative establishment of several new genera for East Asian sorboid species, as proposed by K. Rushforth (2018, 2019), was not supported due to polyphyly. Consequently, the selected taxa encompassed the full range of both generic and hybridogenous entities recognised within the group.

A complete list of the investigated taxa and their abbreviations used in the figures is provided in Table 1. In this work, it was adopted the classification of S.L. Mosyakin *et al.* (2022; 2025), which subsumes the sorboid genera *Aria, Torminalis, Chamaemespilus*, and the hybrids between them (hybrid genera and nothogenera) into a single genus, *Aria*. Consequently, a total of 49 species-level taxa were included in the observations, representing all genus-level sorboid plants: *Aria, Aronia, Cormus, Hedlundia, Micromeles, and Sorbus*. This also encompassed the nothogenera: ×*Amelasorbus,* ×*Arsorbus,* ×*Pyraria,* ×*Sorbaronia,* ×*Sorbocotoneaster,* and ×*Sorbopyrus*.

Table 1. Sorboid taxa included in the investigation

Taxon	Abbreviation
×*Amelasorbus jackii* Rehder	ASj
×*A. raciborskiana* Browicz & Bugala	ASr
Aria adeana (N. Mey.) Mosyakin, Fedor. & McNeill	Aad
A. albovii (Zinzerl.) Mezhenskyj	Aal
A. bristoliensis (Wilmott) Mosyakin, Fedor. & McNeill	Abr
A. buschiana (Zinzerl.) Mezhensky	Abu
A. chamaemespilus (L.) Host	Ach
A. devoniensis (E.F. Warb.) Mosyakin, Fedor. & McNeill	Ade
A. edulis (Willd.) M.Roem.	Aed
A. fedorovii (Zaikonn.) Mezhenskyj	Afe
A. latifolia (Lam.) M. Roem	Ala
A. pannonica (Kárpáti) Sennikov & Kurtto	Apa
A. subfusca (Ledeb. ex Nordm.) Mosyakin, Fedor. & McNeill	Asf
A. torminalis (L.) Beck	Ato
A. sudetica (Tausch) Beck	Asd
Aronia arbutifolia (L.) Pers.	Aar
A. melanocarpa (Michx.) Elliott	Ame
A. ×*prunifolia* (Marshall) Rehder	Apr
×*Arsorbus thuringiaca* (Nyman) Z.H. Feng & Su Liu	ASt
Cormus domestica L.	Cdo
Hedlundia borbasii (Jáv.) Sennikov & Kurtto	Hbo
H. hostii (J. Jacq. ex Host) Mosyakin, Fedor. & McNeill	Hho
H. hybrida (L.) Sennikov & Kurtto	Hhy
H. intermedia (Ehrh.) Mosyakin, Fedor. & McNeill	Hin
H. kuznetzovii (Zinserl.) Mezhenskyj	Hku
H. liljeforsii (T.C.G. Rich) Mosyakin, Fedor. & McNeill	Hli
H. mougeotii (Soy.-Will. & Godr.) Sennikov & Kurtto	Hmo
H. takhtajanii (Gabrielian) Mezhenskyj	Htk
H. tamamschjanae (Gabrielian) Mezhenskyj	Htm
H. teodori (Liljefors) Sennikov & Kurtto	Hte
Micromeles alnifolia (Siebold & Zucc.) Koehne	Mal
M. megalocarpa (Rehder) Mezhenskyj	Mme

Table 1, Continued

Taxon	Abbreviation
×*Pyraria irregularis* (Münchh.) C.A.Wimm.	PAi
×*Sorbaronia fallax* (C.K.Schneid.) C.K.Schneid. subsp. *fallax*	SAf
×*S. f.* subsp. *mitschurinii* (A.K.Skvortsov & Maitul.) Stalažs	SAm
×*S. kovalevii* Mezhenskyj	SAk
×*Sorbocotoneaster pozdnjakovi*i Pojark.	SCp
×*Sorbopyrus kurjanovii* Mezhenskyj, nom. nud. (= *Sorbus aucuparia* L.× *Pyrus communis* L.)	SPk
Sorbus americana Marshall	Sam
S. ×*arnoldiana* Rehder	Sar
S. aucuparia L.	Sau
S. commixta Hedl.	Sco
S. commixta Hedl. × *S. monbeigii* (Cardot) N.P.Balakr.	Scm
S. decora (Sarg.) C.K.Schneid.	Sde
S. koehneana C.K.Schneid.	Sko
S. maderensis (Lowe) Dode	Sma
S. rehderiana Koehne	Sre
S. sambucifolia (Cham. & Schlecht.) M.Roem	Ssa
S. serotina Koehne	Sse

Note: abbreviations are used in figures
Source: developed by the authors

The development of the phenological coding system for sorboid plants was based on existing BBCH scales established for other members of the *Malinae*. Specifically, the framework drew upon the descriptors for *Malus domestica* (Meier *et al.*, 1994; Martínez *et al.*, 2019), *Pyrus communis* (Meier *et al.*, 1994), *Eriobotrya japonica* (Martinez-Calvo *et al.*, 1999), *Cydonia oblonga* (Martínez-Valero *et al.*, 2001), and *Crataegus germanica* (Atay, 2013). Due to the specific biological traits of sorboid taxa and recent extreme climatic shifts, the standard scale was significantly adapted and expanded. Furthermore, the technical descriptions were revised for stylistic and grammatical clarity to ensure international standardisation.

Results and Discussion

The standard BBCH scale for pome fruit (Meier *et al.*, 1994; Meier, 2001) was substantially adapted to reflect the biological characteristics of sorboid taxa and their developmental dynamics under changing climatic conditions. The proposed version consists of eight principal growth stages and forty-five secondary stages (Table 2). The primary modifications involve morphological refinements of bud and inflorescence descriptions, the introduction of a numerical system for recording multiple polycyclic (proleptic) growth flushes, and the redefinition of several late-season stages based on physiological rather than purely visual criteria. Detailed justification for these adjustments is provided in the subsequent sections, grouped by principal growth stages.

The onset and duration of phenological stages in plants are primarily determined by the air temperature regime. Due to global warming, significant deviations from the long-term climatic norm are being observed. This was particularly evident during the 2024-2025 period (Table 3).

Table 2. BBCH growth stages of sorboid plants

Code	Stage, description
	Principal growth stage 0: Leaf bud development
00	Dormancy: leaf buds and the thicker inflorescence buds closed; covered by brown, reddish-brown, or olive-coloured scales
01	Beginning of leaf bud swelling: bud visibly swollen; bud scales elongated with light-coloured patches
03	End of leaf bud swelling
07	Beginning of bud burst: first green leaf tips just visible
09	Leaf tips visible: leaf tips approx. 5 mm above bud scales
	Principal growth stage 1: Leaf development
10	First leaves visible: green leaf tips 10 mm above bud scales; first leaves separating
11	First true leaves unfolded
15	Most leaves unfolded; full size not yet reached
19	First leaves fully expanded
	Principal growth stage 3: Shoot development
31	Beginning of shoot growth: axes of developing shoots visible
32	Shoot approx. 20% of final length
35	Shoot approx. 50% of final length
39	Shoot reach approx. 90% of final length: the terminal bud has begun to form; shoot tip remains herbaceous and non-lignified
	Principal growth stage 5: Inflorescence emergence
51	Inflorescence bud swelling: bud scales elongated with light coloured patches.
52	End of bud swelling: light coloured, bud scales visible
53	Bud burst: leaf tips enclosing flower clusters visible
54	First leaves separating: leaf tips 10 mm above scales
55	Flower bud visible (still closed)
56	Green bud stage: individual flower separating
57	White/pink/red bud stage: flower stalks and petals elongating
58	Early balloon stage: individual flowers enlarged but remain closed
59	Balloon stage: petals forming a hollow ball (just before opening)
	Principal growth stage 6: Flowering
60	First flowers open (sporadic)
61	Beginning of flowering: appox. 10% of flowers open
63	Appox. 30% of flowers open
65	Full flowering: at least 50% of flowers open
66	Beginning of flower fading: first petals fading or beginning to fall
67	Flowers fading: at least 50% of petals fallen, withered or brown, flowers no longer functional
69	End of flowering: all petals fallen, withered or brown (often still attached).
	Principal growth stage 7: Development of fruit
71	Fruit set: ovary growing; abscission of unfertilised or defective ovaries may occur
73	Second fruit fall (facultative)
75	Fruit approx. half final size
77	Fruit approx. 70% final size
79	Fruit reached final size
	Principal growth stage 8: Maturity of fruit
81	Beginning of ripening: first appearance of specific colour
85	Advanced ripening: increase in intensity of specific colour
87	Fruit ripe for picking: typical size and specific colour reached

Table 2, Continued

Code	Stage, description
89	Fruit ripe for consumption: optimum flavour and firmness reached. (In certain taxa, this stage is attained only after the process of bletting)
	Principal growth stage 9: Senescence, beginning of dormancy
90	Fruit overripe: fruit abscission begins; remaining fruits lose turgor and undergo shrivelling
91	Shoot growth completed: terminal bud set; foliage still fully green
92	Beginning of leaf discolouration: onset of leaf yellowing or reddening characteristic of the species
93	Beginning of leaf fall: the abscission layer formed; first leaves start to drop
95	Advanced leaf fall: approx. 50% of leaves fallen; significant discolouration of remaining foliage
97	End of leaf fall: all leaves fallen (marks the start of winter dormancy)
99	Winter dormancy: full metabolic rest

Note: in the event of secondary or tertiary growth flushes (proleptic growth), stages 31-39 recorded with corresponding sequence indices (e.g., 31-II, 39-II); in the event of secondary or tertiary flowering flushes (off-season bloom), stages 60-69 are recorded with corresponding sequence indices (e.g., 61-II, 65-II)
Source: developed by the authors based on U. Meier *et al*. (1994), and U. Meier (2001)

Table 3. Comparison of mean temperatures in Kyiv

Month / Indicator	Climate norm (1991-2020), °C	2024, °C	2025, °C
January	-3.2	-2.6	+2.1
February	-2.3	+2.9	-3.7
March	+2.5	+4.8	+7.4
April	+10.0	+12.8	+11.1
May	+15.8	+16.3	+13.6
Average annual temperature	+9.0	+11.4	+10.4

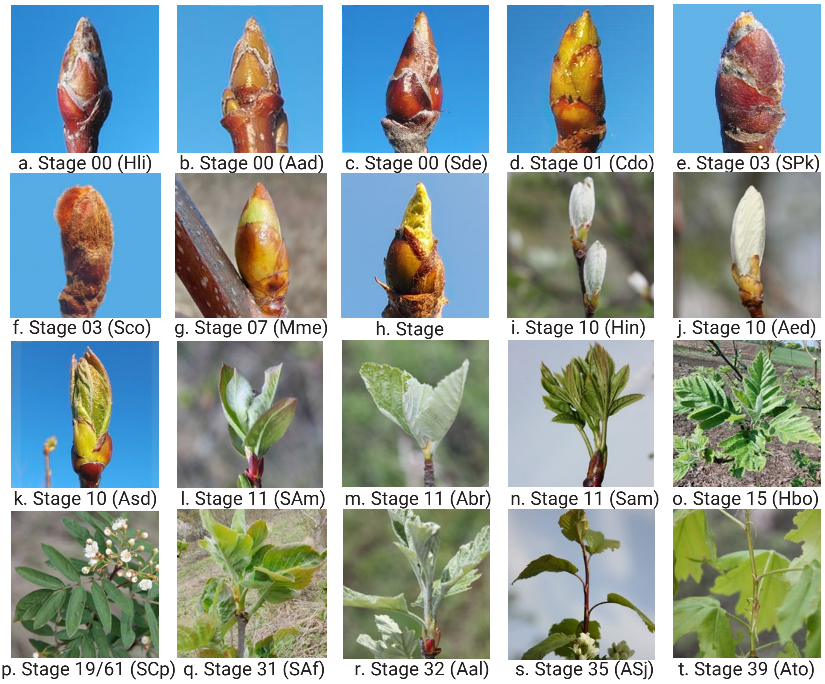
Source: data of the B. Sreznevskyi Central Geophysical Observatory

In 2024, the mean temperature in February was positive rather than negative, which is atypical for the regional climate. Furthermore, January and March 2025 were the warmest on record, with 26 temperature records documented during this period. Such substantial thermal anomalies and the resulting extension of the growing season necessitated the adaptation of the BBCH scale. While Table 2 presents the complete extended BBCH scale for sorboid plants, the specific biological and methodological rationale for key modifications requires detailed explanation. The following subsections address these adaptations systematically, grouped by principal growth stages.

Principal growth stage 0-3 (Fig. 1). According to U. Meier *et al.* (1994) and U. Meier (2001), in the BBCH scale for pome fruits, both closed leaf buds and inflorescence buds are designated by the same code 00 within principal growth stage 0. However, while principal growth stage 0 further describes leaf bud development, a separate principal growth stage 5 (inflorescence emergence) is allocated for the development of inflorescence buds. Principal growth stages 1 and 2 follow stage 0 and describe the development of leaves and shoots, whereas principal growth stages 6 and 7 follow stage 5 to describe the development of flowers and fruits. Among the investigated taxa, *Sorbus sambucifolia* and ×*Sorbocotoneaster pozdnjakovii* consistently exhibit the earliest onset of bud swelling, bud burst, and leaf development, whereas these stages occur noticeably later in *Aria adeana* (Fig. 1b), *A. bristoliensis*, *A. edulis*, *A. pannonica*, *Cormus domestica*, *Hedlundia liljeforsii* (Fig. 1a), *H. takhtajanii*, *H. tamamschjanae*, ×*Sorbopyrus kurjanovii*, *Sorbus americana*, *S. koehneana*, and several other taxa, reflecting pronounced interspecific variation in growth rhythm.

The standard BBCH definition of stage 39 in pome fruits ("Shoots reach about 90% of final length") primarily reflects linear growth and does not adequately distinguish between temporary growth cessation and the onset of structural maturation. A physiological criterion was therefore introduced in this study: the initiation of terminal bud formation while the shoot tip remains herbaceous and non-lignified. This modification allows clear differentiation between the mid-summer pause in elongation (stage 39) and the definitive completion of shoot growth in autumn (stage 91).

Stage 39 describes the mid-summer cessation of linear growth and is functionally distinct from stage 91 ("shoot growth completed") by the presence of a soft, herbaceous tip, as opposed to the fully lignified wood and dormant bud set observed in autumn. To account for the dynamic nature of vegetative development, the BBCH scale was adapted to record multiple growth flushes. While the first flush typically concludes in mid-summer (stage 39-I), subsequent proleptic growth (secondary and tertiary flushes) was documented by repeating the stage 3 sequence with Roman numeral indices. This differentiation is particularly important for assessing winter hardiness, as late-season flushes (e.g., stage 39-III) often fail to reach full lignification before the onset of dormancy (stage 91).



a. Stage 00 (Hli) b. Stage 00 (Aad) c. Stage 00 (Sde) d. Stage 01 (Cdo) e. Stage 03 (SPk)

f. Stage 03 (Sco) g. Stage 07 (Mme) h. Stage i. Stage 10 (Hin) j. Stage 10 (Aed)

k. Stage 10 (Asd) l. Stage 11 (SAm) m. Stage 11 (Abr) n. Stage 11 (Sam) o. Stage 15 (Hbo)

p. Stage 19/61 (SCp) q. Stage 31 (SAf) r. Stage 32 (Aal) s. Stage 35 (ASj) t. Stage 39 (Ato)

Figure 1. BBCH growth stages for leaf bud, leaf, and shoot development of sorboid plants
Source: authors' photo

Principal growth stage 5-6 (Fig. 2). The developmental stages of inflorescence buds in sorboid plants closely parallel those of leaf buds, particularly during swelling and bud burst (Fig. 2a-Fig. 2d). However, the horticultural term "mouse-ear stage" (codes 10 and 54), commonly applied to pome fruits, is inappropriate for sorboid taxa and was therefore excluded. Instead, the neutral and morphologically accurate designation "first leaves visible" was adopted, ensuring clarity and reproducibility in phenological observations. Stage 57 was refined to "white/pink/red bud stage", capturing the interspecific variation in petal colouration and enhancing the accuracy of early floral coding for diverse taxa (Fig. 3l). To improve the resolution of early floral development, an "Early balloon stage" (stage 58) was introduced prior to the standard "balloon stage" (stage 59), characterised by enlarged but still closed individual flowers (Fig. 2m). Stage 60 marks the sporadic opening of the first flowers, while the beginning (stage 61) and full flowering (stage 65) were defined as approximately 10% and at least 50% of flowers open, respectively (Fig. 2n, Fig. 2q). Although most sorboid species exhibit white petals, pink-flowered taxa include *Aria chamaemespilus* and its derivatives *A. sudetica* and *Hedlundia hostii*, underscoring the ornamental value of this phenological phase within the *Malinae* (Fig. 2.36).


a. Stage 50 (The) b. Stage 51 (Cdo) c. Stage 52 (Ala) d. Stage 52 (Hho) e. Stage 54 (Asd)
f. Stage 54 (Sre) g. Stage 55 (Apr) h. Stage 55 (Sar) i. Stage 56/15 (Hku) j. Stage 56/15 (Ssa)
k. Stage 56/15 (SAf) l. Stage 57/19 (Mal) m. Stage 59 (Ame) n. Stage 60 (Sse) o. Stage 63 (Sko)
p. Stage 63 (Ach) q. Stage 65 (Hhy) r. Stage 66 (Aar) s. Stage 67 (Sau) t. Stage 69 (Abu)

Figure 2. BBCH growth stages for reproductive development and flowering of sorboid plants
Source: authors' photo

Flower senescence is initiated at stage 66, when the first petals fade or abscise (Fig. 2r). Stage 67 ("flowers fading") corresponds to the loss or withering of at least 50% of petals, and stage 69 ("end of flowering") is reached once all petals have fallen or fully withered, even if a few remain temporarily attached (Fig. 2s, Fig. 2t). This standardised approach provides a reliable framework for comparing flowering dynamics across taxa and for guiding management decisions in fruit production, ornamental horticulture, and phenological research.

Principal growth stage 7-8 (Fig. 3a-Fig. 3o). Fruit development in sorboid plants occurs at various times depending on the genotype. This phase, like other phenological phases, is strongly influenced by environmental conditions. Although 2024-2025 were generally warmer than average, May 2025 proved to be colder than normal, which somewhat slowed the rapid plant development that had commenced in March. Consequently, the early onset of vegetation did not result in early fruit ripening. The fruits of sorboid plants exhibit great diversity in colouration. Most species possess light or dark red and red-orange fruits, which occur in ×*Amelasorbus, Aria* (Fig. 3k), ×*Arsorbus, Hedlundia* (Fig. 3l), *Micromeles,* ×*Sorbocotoneaster,* ×*Sorbopyrus,* and *Sorbus* (Fig. 3o). While the fruits of ×*Amelasorbus jackii* are typically dark red, the accession in the collection produces dark blue fruits, suggesting a possible backcross with *Amelanchier*. White fruits are found in *Sorbus koehneana* and a collection accession of *S. maderensis* (Fig. 3m), while white fruits with a pink blush are characteristic of *S.* ×*arnoldiana* 'Maiden Blush'. Yellow fruits occur in *S. commixta* × *monbeigii* 'Joseph Rock' and one of the accessions of *S. decora*. *Cormus domestica* and ×*Pyraria irregularis* possess a yellow ground colour with a blush of varying intensity as an overcolour. Black fruit colouration is typical of *Aronia melanocarpa*, ×*Sorbaronia fallax* subsp. *mitschurinii*, and some accessions of ×*S. fallax* subsp. *fallax* (Fig. 3n), though the latter also includes burgundy-fruited cultivars. Dark purple fruits are found in *Aronia* ×*prunifolia* and ×*Sorbaronia kovalevii* (Fig. 3p), while brown fruits are characteristic of *Aria devoniensis, A. torminalis*, and *Micromeles megalocarpa*. At the early stage of fruit growth, the abscission of unfertilised or defective ovaries may occur (stage 71) (Fig. 3c, Fig. 3d). Stage 73 ("second fruit fall"), while typical of pome crops, is less pronounced in sorboid plants. The ovary and young fruits are green; therefore, the appearance of specific colouration indicates the beginning of ripening (stage 81), which gradually increases in intensity. Ripe fruits (stage 87) (Fig. 3m-Fig. 3o) reach full size and acquire typical colouration and flavour. According to O. Raspé *et al.* (2000), most *Sorbus* species are characterised by bitterness due to specific glycosides, primarily parasorbic acid, which reduces their palatability to the point of being inedible in their raw state.

Stages 87 and 89 correspond to harvest maturity and consumer ripeness for pome fruits, respectively. However, for autumn and winter apple and pear varieties, stage 89 is a commercial characteristic rather than a phenological phase. In summer varieties, harvest maturity and consumer ripeness coincide, whereas for autumn and winter varieties, consumer ripeness occurs significantly later, potentially even during the following growing season. This stage is determined using a complex of chemical and physical methods (starch-iodine test, flesh firmness, and soluble solids content). Some species within the *Malinae*, such as medlar (*Crataegus germanica*), produce fruits that are entirely inedible at stage 87 due to their hard flesh and intense astringency caused by phenolic compounds (Atay, 2013). They become palatable only after a ripening process called bletting, during which the macerated flesh acquires a delicate consistency and sweet flavour. This process can occur either on the tree or during storage after harvest. A similar progression towards consumer ripeness is characteristic of sorboid plants such as *Cormus domestica*.

a. Stage 69 (Hmo)
b. Stage 71 (Asr)
c. Stage 71 (Cdo)
d. Stage 71 (Asd)
e. Stage 75 (Scm)
f. Stage 75 (SCp)
g. Stage 75 (Afe)
h. Stage 77 (Pai)
i. Stage 81 (Sau)
j. Stage 81 (SAf)
k. Stage 85 (Asf)
l. Stage 85 (Htm)
m. Stage 87 (Sma)
n. Stage 87 (SAf)
o. Stage 87 (Sre)
p. Stage 90 (SAk)
q. Stage 91 (Apa)
r. Stage 92 (Ast)
s. Stage 97 (Htk)
t. Stage 90/97 (SAf)

Figure 3. BBCH growth stages for fruit development, ripening, and senescence of sorboid plants
Source: authors' photo

Principal growth stage 9 (Fig. 3p-Fig. 3t). At stage 90, the fruit enters the phase of senescence. The formation of an abscission layer in the stalk causes many fruits to fall naturally. For those that remain on the tree, the primary characteristic is shrivelling – a visible contraction of the skin and flesh caused by significant moisture loss and the breakdown of cellular structures. At this stage, the fruit's internal tissues lose their commercial quality, typical texture, and flavour profile entirely. ×*Sorbaronia fallax* plants produce black fruit that ripen in August and remain on the branches throughout autumn and winter. Although they shrivel and lose some moisture, they retain their value due to their high phenolic compound content. It is essential to distinguish between the enzymatic maceration of the mesocarp at stage 89 and physiological degradation at stage 90 (Fig. 3p). For *Crataegus germanica* and *Cormus domestica*, the breakdown of cellular structures during bletting is a functional requirement for achieving consumer ripeness (stage 89), resulting in a palatable, sweet, and soft texture. Conversely, the degradation observed at stage 90 is a symptom of senescence, characterised by shrivelling and desiccation. While bletting represents the peak of organoleptic quality for these species, stage 90 marks the irreversible loss of commercial and culinary value due to uncontrolled tissue breakdown and moisture loss.

By renaming the standard BBCH stage 95 ("50% of leaves discoloured") to "advanced leaf fall" and stage 97 ("all leaves fallen") to "end of leaf fall", the monitoring focus shifts from transient optical changes to the tangible loss of biomass and the definitive cessation of the tree's assimilatory functions. This modification ensures higher precision in recording the transition to winter dormancy, particularly in sorboid taxa where defoliation often occurs concurrently with, or even precedes, total chlorophyll degradation. While phenological observations are inherently visual, focusing on leaf fall rather than discolouration enhances the methodology by replacing a subjective optical assessment with a quantifiable structural event. For sorboid plants, where autumnal pigmentation can be prolonged and variable, defoliation serves as a more definitive proxy for the completion of the physiological growth cycle.

The vegetative cycle was considered complete once the plants reached stage 97 (Fig. 3s, Fig. 3t). However, it is worth noting the occasional occurrence of marcescence, where withered leaves are retained on the branches throughout the winter dormancy period. While this phenomenon can serve as a distinctive taxonomic or adaptive marker for certain sorboid taxa, it was recorded as a supplementary qualitative observation rather than a formal phenological phase, as it represents a deviation from the typical physiological defoliation sequence. It was concluded that there is no requirement to introduce a separate BBCH code for leaf persistence. Instead, the completion of the vegetative cycle is recorded at stage 97, with the occurrence of marcescence noted as a supplementary qualitative attribute (e.g., marked as "97 m"). This approach avoids overcomplicating the phenological scale while ensuring that this distinctive taxonomic trait is accurately documented without distorting the primary data on the cessation of growth.

In the standard BBCH scale, stage 99 is traditionally defined as "harvested product". However, for sorboid taxa, this definition introduces significant chronological and biological inconsistencies. In many fruit-bearing species, the harvest maturity occurs well before the completion of leaf senescence (stages 95-97). Following a strict numerical sequence would incorrectly place the harvest at the absolute end of the physiological cycle. Principal growth stage 9 is fundamentally dedicated to senescence and dormancy. While harvesting is an agricultural operation, it does not necessarily align with the plant's physiological entry into rest. In several sorboid species, fruits persist on the branches throughout the winter. In such cases, "harvested product" is an irrelevant marker for the plant's natural biological progression. Consequently, stage 99 has been redefined as "winter dormancy". This shift ensures that the scale reflects the definitive cessation of metabolic activity and the attainment of full seasonal rest, providing a logically consistent conclusion to the annual vegetative cycle.

The proposed coding system is applicable across a wide range of sorboid genera and their hybrids, enabling comparative phenological analyses across climatic gradients and management regimes. This framework provides a standardised basis for forest introduction trials, orchard management, winter hardiness assessment, and integration of phenological datasets in broader ecological and climate-oriented research.

The scale for pome fruits, developed by U. Meier *et al.* (1994) for *Malus domestica* and *Pyrus communis*, was incorporated into the BBCH Monograph (Meier, 2001) with minor amendments and additions. In the work of R. Martínez *et al.* (2019), dedicated to one of *Malus domestica* cultivars, this scale is presented with certain adjustments and refinements in the descriptions of some secondary stages. The authors explicitly discard terms such as "mouse-ear stage", "T-stage", and similar horticultural expressions in their descriptions. The use of the "fruit set" description for both stage 69 (belonging to the principal growth stage "flowering") and stage 71 (principal growth stage "fruit development") introduces conceptual ambiguity. They also discard stage 87 "fruit ripe for picking", noting that apples become suitable for harvesting and consumption only at stage 89. Stage 99 is absent from their scale; the phenological sequence concludes at stage 97, defined as "winter rest period". All leaves fallen". The results of this study, despite the biological differences shown between the apple fruit and pears, essentially coincide with those obtained by U. Meier (1997) for the phenological stages of pome fruits. The sequential progression of the main stages of growth indicates that reproductive development partially overlaps with vegetative growth.

R. Martínez-Valero *et al.* (2001) described the phenological stages of the quince tree using the BBCH General Scale in combination with a previous phenological coding system for fruit trees by another author. They defined the secondary stages of the Principal growth stage "flowering" in a manner that differs from the standard BBCH scheme. While in the BBCH scale the opening of the first flowers and the beginning of flowering are marked by codes 60 and 61 respectively, and codes 62 and 65 indicate the opening of 20% and 50% (full flowering) of flowers, in quince the "petals visible" stage is marked with code 61, "petals begin to separate" with code 62, and "open flowers" with code 65. There are also discrepancies between the coding of the "fruit reached final size" stage, which corresponds to code 79 in the BBCH scale, while R. Martínez-Valero *et al.* marked it with code 78. In their system, complete leaf fall is interpreted as the end of vegetation and the onset of winter dormancy and is coded as 93, whereas in the standard BBCH scale, this code denotes only the beginning of leaf fall.

For sorboids, the original descriptions were systematically revised, and several new secondary stages were introduced to provide finer resolution of inflorescence development and shoot maturation. Specifically, the introduction of stage 58 "early balloon stage" and the redefinition of stage 39 allow for a more precise discrimination between closely related phenological events compared to the baseline scale. While our study introduces several morphological refinements and additional stages for sorboid plants, E. Atay (2013) adhered strictly to the standard BBCH scale for medlar, without introducing any morphological refinements or adjustments. He also fully accepted stage 89 "fruit ripe for consumption: fruit have typical taste and firmness" without addressing the specific physiological features of the onset of consumer ripeness in medlar fruits.

The description of the phenological stages of the loquat tree was established according to the BBCH scale by J. Martinez-Calvo *et al.* (1999). The loquat tree differs from other pome fruit tree species in that it has persistent leaves and three flushes of growth per year;

flowering occurs during autumn and winter, and fruit harvest occurs during spring. Considering that the loquat, as a subtropical plant, has differences in growth and development compared to plants of the temperate zone, three mesostages (1-3) were used, corresponding respectively to autumn, spring, and summer growth. Mesostage 0 is used for the generative phase. The authors demonstrated the advantages of applying the BBCH scale over other scales, which allowed loquat varieties to be better characterised. In J. Martínez-Calvo *et al.* (1999), repeated vegetative growth phases within a single growing season are accounted for by subdividing the vegetative phase into mesostages corresponding to the seasons of the year. Three mesostages (1-3) are used to represent autumn, spring, and summer growth, respectively. Within each mesostage, the complete sequence of codes of principal growth stage 0 (010-019, 020-029, 030-039) is repeated, describing identical morphological events of bud development (dormancy, swelling, and bud burst). Thus, in loquat, growth repetition is formalised through seasonal segmentation rather than by distinguishing biologically independent growth flushes. The same morphological stage is assigned different codes depending on the season in which it occurs, which is appropriate for a species with a clearly expressed seasonal growth pattern.

In contrast, in the BBCH-based scale developed for sorboid plants, a fundamentally different principle of scale adaptation is applied. In the event of secondary or tertiary growth flushes, the base BBCH code remains unchanged, while growth repetition is recorded by introducing sequential cycle indices (e.g., 31-II, 39-II, 31-III). This approach enables the documentation of biologically independent growth flushes, irrespective of the calendar season in which they occur. This distinction has important functional and adaptive implications, particularly for assessing shoot maturation and winter hardiness. While preserving the universality and comparability of the BBCH scale, this approach simultaneously extends its descriptive capacity for polycyclic growth in woody plants under changing climatic conditions. The same coding principle is also applied to cases of off-season flowering.

Conclusions

The extended BBCH scale developed in this study provides a comprehensive, standardised, and biologically justified framework for the detailed description of phenological growth stages across the diverse sorboid group. By assigning identical codes to analogous principal and secondary growth stages, the scale facilitates high-resolution bioclimatic monitoring and ensures terminological consistency, comparability, and reproducibility in international scientific communication. The proposed framework fills a critical methodological gap, as no unified BBCH-based system previously existed for sorboid taxa.

Significant modifications were introduced to account for the unique developmental dynamics of sorboids, most notably their capacity for repeated proleptic shoot growth flushes, which have direct implications for plant stability, winter survival, and management under variable climatic conditions. The introduction of secondary growth indices (I, II, III) provides a concise diagnostic tool for recording late-season growth flushes that often remain insufficiently lignified, thereby enabling an objective assessment of frost susceptibility, shoot dieback risk, and long-term structural quality. The replacement of subjective optical criteria (leaf discolouration) with clearly identifiable structural and physiological markers, such as leaf fall and terminal bud formation, substantially improves the operational clarity and consistency of phenological observations. Renaming stage 97 to "end of leaf fall" and stage 99 to "winter dormancy" aligns the BBCH framework with functionally meaningful phenological thresholds, facilitating accurate identification of the completion of assimilatory activity and the onset of dormancy.

The explicit distinction between harvest maturity (stage 87) and consumer ripeness (stage 89) is particularly important for sorboid species with physiologically delayed fruit palatability, such as *Cormus domestica*, and prevents the conflation of biological phenological phases with purely agronomic or technological criteria, thereby preserving the conceptual and physiological integrity of the BBCH system. Furthermore, the clear separation of consumer ripeness (stage 89) from fruit senescence (stage 90) ensures correct interpretation of late-season fruit persistence in several sorboid species.

Overall, this extended BBCH framework presented here constitutes an effective and versatile tool for the management of sorboid genetic resources, long-term phenological monitoring, winter hardiness assessment, and integrated horticultural, silvicultural, and ornamental plant planning, as well as for the assessment of adaptive responses of woody perennials to ongoing climate change.

Furthermore, the indexing approach and morphological refinements established in this study provide a methodological template for the future adaptation of BBCH scales for other underutilised or taxonomically complex woody perennials. Future research should focus on the practical validation of this scale across broader geographic ranges to quantify the correlation between specific secondary stages and the adaptive capacity of sorboid hybrids to extreme weather events.

Acknowledgements

None.

Funding

None.

Conflict of Interest

None.

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Фенологічні фази росту рослин сорбоїдної групи підтриби *Malinae* (*Rosaceae*) за шкалою BBCH

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Анотація. Розробка уніфікованої системи для моніторингу стадій розвитку сорбоїдних рослин підтриби *Malinae* має велике економічне та екологічне значення. Метою дослідження було розробити комплексну фенологічну систему для сорбоїдних рослин на основі розширеної шкали BBCH. Дослідження проводилося протягом 2024-2025 років на колекційних ділянках Національного університету біоресурсів і природокористування України і охоплювало 49 таксонів на рівні видів, що представляли роди *Aria*, *Aronia*, *Cormus*, *Hedlundia*, *Micromeles* і *Sorbus*, а також нотороди ×*Amelasorbus*, ×*Arsorbus*, ×*Pyraria*, ×*Sorbaronia*, ×*Sorbocotoneaster* та ×*Sorbopyrus*. Методологія передбачала регулярні польові спостереження за окремими рослинами, а стадії розвитку документувалися за допомогою систематичної фотозйомки на місці протягом усього вегетаційного періоду. Розробка розширеної шкали базувалася на принципах десяткової системи кодування BBCH і включала вдосконалені морфологічні дескриптори як для вегетативних, так і для репродуктивних органів. Щоб врахувати вторинні та третинні цикли росту, які спостерігаються в умовах останніх кліматичних змін, було впроваджено систему подвійної індексації для документування послідовних пролептичних пагонів. Запропонована шкала складалася з восьми основних стадій росту, які суттєво адаптовані для відображення специфічних біологічних особливостей сорбоїдних рослин. Ключові зміни включали вдосконалені дескриптори для появи бруньок і суцвіть, числову систему для реєстрації множинних спалахів росту (стадії 31-39) та переосмислення стадій пізнього сезону з метою акцентування уваги на структурних і фізіологічних маркерах, таких як опадання листя і зимовий спокій, а не на тимчасових оптичних ознаках. Ця стандартизована система кодування забезпечує високу точність біокліматичного моніторингу, оцінки зимостійкості та міжнародного обміну науковими даними про генетичні ресурси сорбоїдних рослин. Результати дослідження можна використовувати на практиці для моніторингу розвитку сорбоїдних рослин у лісовому господарстві, садівництві та при збереженні біорізноманіття

Ключові слова: *Aria*; *Aronia*; *Cormus*; *Hedlundia*; *Micromeles*; *Sorbus*; міжродові гібриди; нототксони; фенологія

УКРАЇНСЬКИЙ ЖУРНАЛ ЛІСІВНИЦТВА ТА ДЕРЕВИНОЗНАВСТВА

Науковий журнал

Том 16, № 4. 2025

Заснований у 2010 р. Виходить чотири рази на рік

Оригінал-макет видання виготовлено
у відділі науково-технічної інформації
Національного університету біоресурсів і природокористування України

Відповідальний редактор:
Н. Шевченко

Підписано до друку 27 листопада 2025 р. Формат 70*100/16
Умов. друк. арк. 7,3
Наклад 100 прим.

Адреса видавництва:
Національний університет біоресурсів і природокористування України
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https://forestscience.com.ua/uk

UKRAINIAN JOURNAL OF FOREST AND WOOD SCIENCE

Scientific journal

Volume 16, No. 4. 2025

Founded in 2010. Published four times per year

The original layout of the publication is made in the Department of Scientific
and Technical Information of National University of Life
and Environmental Sciences of Ukraine

Managing editor:
N. Shevchenko

Signed for print of November 27, 2025. Format 70*100/16
Conventional printed pages 7.3
Circulation 100 copies

Publisher's address:
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
Tel.: +38(044)-258-42-63
E-mail: fws@forestscience.com.ua
https://forestscience.com.ua/en