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Impact of climate change on populations and resources of *Convallaria majalis*

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This study investigates the long-term effects of climate change on the populations and resource potential of *Convallaria majalis* L. in deciduous forest communities of Kyiv region, Ukraine. From 2005 to 2024, five monitoring plots located in oak-dominated phytocenoses were observed to assess changes in species composition, plant population parameters, and resource indicators due to increasing temperatures and decreasing precipitation. Over the study period, the structure of forest communities underwent notable transformations, including a decline in tree layer density – especially *Pinus sylvestris, Robinia pseudoacacia*, and *Populus alba* – and an increased dominance of shrub species such as *Sambucus nigra, Euonymus europaeus*, and *Crataegus rhipidophylla*. Simultaneously, a shift was observed in the herbaceous layer towards species with broader ecological amplitude and higher tolerance to environmental stressors. The analysis of *C. majalis* populations revealed a substantial reduction in projective cover, shoot density, and raw material stock density across all monitoring areas, with the most significant changes recorded after 2014. Although average plant height and shoot weight varied inconsistently across sites, sometimes increasing due to reduced competition, these parameters were also strongly influenced by meteorological conditions. Correlation analyses demonstrated a pronounced positive relationship between precipitation during the April–June growing season and plant height and biomass, while elevated temperatures, particularly from the previous year, exerted a stable negative influence on shoot density and resource availability. The results highlight the vulnerability of *C. majalis* to climate-induced hydrothermal stress and point to the cumulative effects of coenotic transformation, drought, and heat on its reproductive capacity and spatial structure. Continued climatic changes may lead to a reduction in the species' distribution, fragmentation of its populations, and depletion of its natural resources. These findings underscore the urgent need for long-term ecological monitoring, adaptive conservation strategies, and sustainable management practices to preserve valuable medicinal plant populations under changing environmental conditions.

Keywords: climate change; forest communities; diversity; *Convallaria majalis*; resources.

Introduction

The reaction of plants to climate change is determined, on the one hand, by the life strategy of their populations and, on the other hand, by the degree of limiting influence of environmental factors on them (Hamann et al., 2021). Elucidating such a relationship is essential for medicinal plant resources sourced from the natural environment. To predict possible changes in the structure of plant populations, it is crucial to consider the defining biological, ecological, and coenotic characteristics of a particular species while observing the trend of changes in a specific phytocenosis and the environmental indicators upon which these changes significantly depend. Understanding the complex relationship between plant adaptive properties and climate change is paramount to ensuring the sustainable use and conservation of phytosystems in the face of contrasting climate patterns (Kanta et al., 2024).

Populations of plant species, which are essential components of stable forest phytocenoses, are inherently vulnerable when environmental conditions change (Kijowska-Oberc et al., 2020; Baldrian et al., 2023; Klisz et al., 2023). This vulnerability is particularly noteworthy for herbaceous plant species, such as *Convallaria majalis* L. This species constitutes a permanent part of the herbaceous layer in forest communities belonging to the classes *Vaccinio-Piceetea* Br.-Bl. in Br.-Bl. et al. 1939, *Quercetea robori-petraeae* Br.-Bl. ex Tx. ex Oberd. 1957, and *Carpino-Fagetea sylvaticae* Jakucs ex Passarge 1968, which are widely distributed across the forest zone of Ukraine. The economic value of *C. majalis* arises from its medicinal and decorative properties. In the context of environmental changes induced by anthropogenic pressure on phytocenosis and climate change, a steady trend towards the degradation of its cenopopulations and depletion of raw materials has emerged in all distribution areas (Minarchenko, 2017). Studying the dynamics of plant populations over a long period is essential for understanding how species adapt to changing habitat conditions and clarifying the threats and rates of destructive changes in plants and communities for scientifically based sustainable use of their resources in situations of rapid climate change (Puchałkaet al., 2023; Vaceket al., 2023; Wanga et al., 2023).

Lily of the valley is one of the species in Europe that is underrepresented in cenopopulations and raw material productivity studies. Some phenological studies of the influence of temperature on the onset of its flowering (March–April) have already been documented (Szabó et al., 2016). Other studies have shown climate niche shifts for *Convallaria majalis* and assessed the threat level under various climate change scenarios (Puchałka et al., 2023). However, changes in the morphometric parameters and structure of the *C. majalis* cenopopulations, in conjunction with changes in the structure of the forest phytocenosis due to climate change, have not been studied.

Considering the significant value of this species as a source of natural medicinal plant resources and the requirements of national legislation regarding the need for its balanced use and protection, we have been conducting research on the dynamics of cenopopulations and resources of *C. majalis* for several decades (Minarchenko, 2011). Given the many adaptive biological advantages (predominant vegetative reproduction, protection of vegetative organs from adverse conditions during the dormant period, etc.) that allow lily of the valley plants to maintain coenotic positions for extended periods, negative changes in its populations are relatively slow without catastrophic changes in the habitat. Therefore, predicting the dynamics of the structure and resource significance of cenopopulations of this species necessitates a substantial amount of accurate data regarding both the state of the phytocenosis and the abiotic indicators that determine these changes.

In this work, based on the results of our years of observations, we will demonstrate the changes in the structure of phytocenosis and the morphometric and weight indicators of *C. majalis* plants in five monitoring areas situated in communities dominated by *Quercus robur* L. and including *Pinus sylvestris* L., *Robinia pseudacacia* L., or *Populus alba* L. in separate monitoring areas. This area is located on the border of two zones: Polissia and Forest-Steppe, where mixed forests with a dominance of *Pinus sylvestris* or *Quercus robur* are widespread. Some researchers claim that the high morphometric indicators of *C. majalis* in the *Pinetum* (*sylvestris*) *coryloso* (*avellanae*)–*urticosum* (*dioici*) communities indicate the proximity of such habitats to the ecological and coenotic optimum of this species (Penkovska, 2019).

By summarizing the results of our long-term research, we aim to create a comprehensive picture of the relationship between the dynamics of populations and the resources of separate plant species and phytocenoses as a whole under changes in specific meteorological factors.

Materials and methods

The research was conducted within Kyiv region, Buchansky district (Table 1, Fig. 1).

Table 1
The monitoring areas of *Convallaria majalis*

Locality	Number of the monitoring area	Coordinates of the monitoring area
Kyiv region, Buchansky district, vicinity of the village of Mykolaivka	1	50°27'33'' N 30°02'28'' E
	2	50°27'30'' N 30°02'27'' E
	3	50°27'32'' N 30°02'22'' E
	4	50°27'31'' N 30°02'16'' E
	5	50°27'29'' N 30°02'14'' E

Monitoring areas (MA) for studying changes in the structure of *C. majalis* cenopopulations and resources were established following the requirements of the monitoring methodology (Minarchenko et al., 2008) in 2005 in the coenosis of the class *Quercetea robori-petraeae*, the union *Convallario majalis-Quercion roboris* Shevchyk et Solomakha in Shevchyk, Solomakha et Voityuk 1996, the association *Melico nutantis–Quercetum roboris* Shevchyk et Solomakha in Shevchyk, Solomakha et Voityuk 1996. The sizes of the monitoring areas were 100−250 m^2.

Fig. 1. Scheme of the location of the monitoring areas

The first two (№ 1–2) MAs were near to each other, while MAs 3–5 were 700 m from the first. Geobotanical descriptions, morphometric data, and weight indicators were collected at various intervals in 2005, 2010, 2014, 2018, 2021, 2023, and 2024.

To clarify the dynamics of the resources of the studied species under the influence of climate change, the following resource indicators were determined (projective cover of *C. majalis*, average plant height, shoot density, raw material stock density, average shoot weight) in 10 replicates within monitoring areas. The data were processed using the software PAST (Hammer et al., 2001).

Meteorological data on the mean monthly air temperature and monthly precipitation of research MAs were obtained from the Branch State Archive of Hydrometeorological Observation Materials of the Boris Sreznevsky Central Geophysical Observatory of the State Emergency Service of Ukraine and from the site http://cgo-sreznevskyi.kyiv.ua/uk/diialnist/klimatolohichna/klimatychni-dani-po-kyievu (Figs. 2, 3). We used data from the Kyiv meteorological station, as it is the closest station located near the studied monitoring areas (Figs. 2, 3). In our research, we took into account such meteorological indicators as the amount of precipitation for the current year and the previous year, sum of mean average monthly temperatures for the current year and the previous year. The period of active growth and development of *C. majalis* is April–June, so we took into account the amount of precipitation for April–June of the current year and the previous year, and the sum of mean monthly temperatures for April–June of the current year.

The dependence of resource parameters on meteorological data was assessed using correlation analysis. The accepted level of significance was set at $P < 0.05$. Analyses were performed with Statistix v. 10.0 (Analytical Software, Tallahassee, FL, USA).

Results

During the observation period (2005–2024), certain changes in the structure of the phytocoenosis occurred at the monitoring areas, most notably in the herbaceous layer. The structure and species diversity are similar, with some differences between monitoring areas 1–2 and 3–5. However, during certain periods, they fluctuated. The species diversity is 59 species, with a range of 26 to 40 species at different monitoring sites. *Quercus robur* dominates in the tree layer of all monitoring sites, but the proportion of other tree species varies somewhat. The tree layer has gradually thinned in all monitoring areas due to the death of *Pinus sylvestris* L., some *Robinia pseudoacacia* L. trees in MA 1, and all *Populus alba* trees in MA 4, 5.

The shrub layer is well developed, featuring *Crataegus rhipidophylla* Gand, *Euonymus europaeus* L. and *Sambucus nigra* L. as the most commonly found species. Moreover, there is a notable tendency for its increase, particularly in MA 4. The role of *Corylus avellana* L., *Euonymus europaeus*, and *Frangula alnus* Mill. has gradually increased at MA 1–2, while at MA 4–5, there is an increased participation of *Sambucus nigra* L. and *C. rhipidophylla*. The abundance of *Rubus caesius* L. shows some increase in MA 3, 5.

The herbaceous species accounted for over 80% of the total across all monitoring sites. While the species diversity of the herbal layer at some monitoring sites has not changed significantly, the participation of certain species has changed noticeably. Between 28 and 34 herbaceous species were noted in MA 1 and 2, and their numbers remained relatively stable during the observation period. Changes in species participation in the community differed somewhat among the monitoring plots. In particular, *Chelidonium majus* L. and *Urtica dioica* L. demonstrated a stable trend of increasing importance in the herbaceous layer at MA 1–2, with their maximum participation occurring from 2014 to 2021, followed by a noted reversal of this trend. The abundance of *Pteridium aquilinum* (L.) Kuhn, *Lathyrus nigrum* (L.) Bernh., *L. vernus* (L.) Bernh., *Stellaria holostea* L., *Primula veris* L., and *Majanthemum bifolium* (L.) F. W. Schmidt is steadily decreasing in both plots. In MA 1, since 2021, *Betonica officinalis* L. and *Potentilla alba* L. have not been observed, and *Primula veris* has nearly disappeared.

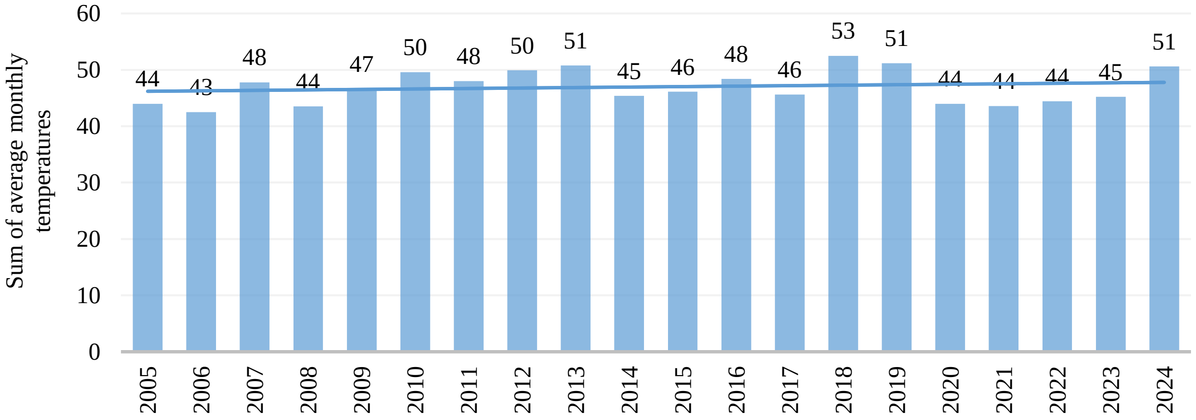

Fig. 2. The sum of mean monthly temperatures for April–June in the study region (°C) for the period 2005–2024 according to data from the Branch State Archive of Hydrometeorological Observation Materials of the Boris Sreznevsky Central Geophysical Observatory of the State Emergency Service of Ukraine and site http://cgo-sreznevskyi.kyiv.ua/uk/diialnist/klimatolohichna/klimatychni-dani-po-kyievuo

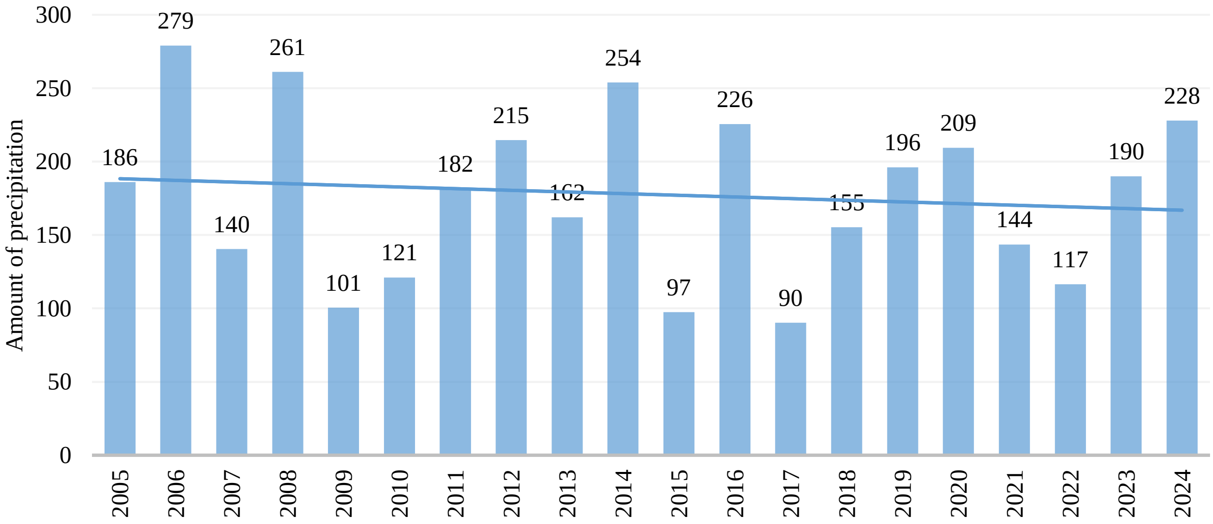

Fig. 3. The amount of precipitation for April–June in the study region (mm) for the period 2005–2024 according to data from the Branch State Archive of Hydrometeorological Observation Materials of the Boris Sreznevsky Central Geophysical Observatory of the State Emergency Service of Ukraine and site http://cgo-sreznevskyi.kyiv.ua/uk/diialnist/klimatolohichna/klimatychni-dani-po-kyievuo

The herbaceous layer in MA 3–5 is characterized by greater diversity than in MA 1–2, there were noted 26–41 herbaceous species. Changes in the participation of most species primarily exhibited a fluctuating nature and were generally not very pronounced. Although most changes in the involvement of herbaceous species in the community were not systemic, stable trends were identified for some species. A sharp increase in the abundance of *Chelidonium majus* in MA 3–4 occurred from 2014 to 2021, followed by a gradual decline; however, the role of *Urtica dioica* continues to grow here (Table 2). During the observation period, *Lilium martagon* L. disappeared from all monitoring areas; under threat of disappearing are *Polygonatum odoratum* (Mill.) Druce and *Iris aphylla* subsp. *hungarica* Waldst. & Kit. In MA5, a slight increase in the abundance of *Digitalis grandiflora* Mill., *Potentilla alba*, and *Fragaria vesca* L. was noted. *Pulmonaria angustifolia* L. and *P. obscura* Dumort are two new species that appeared in the study area. The role of *Lathyrus niger* (L.) Bernh. and *L. vernus* (L.) Bernh. in the community is steadily decreasing (Table 2).

The primary resource parameters of *C. majalis*, such as the projective cover (Fig. 4), the density of partial shoots (Fig. 5), and the density of raw material resources (Fig. 6) in all monitoring areas, significantly decreased during the observation period. Thus, as of 2024, the projective cover on MA 2–3 and 5 has approximately halved, while on MA 4, the projective cover remained unchanged, although this indicator varied across all monitoring sites during the observation period. The density of partial shoots decreased during the observation period by 1.3–1.7 times. Another important indicator of resources of *C. majalis* (the density of raw material stock) decreased by 1.3–2.1 times from 2005 to 2024 in all monitoring areas. In MA 1–2, a continuous massif of lily of the valley broke up into separate aggregations, covering an area of 9–15 m^2.

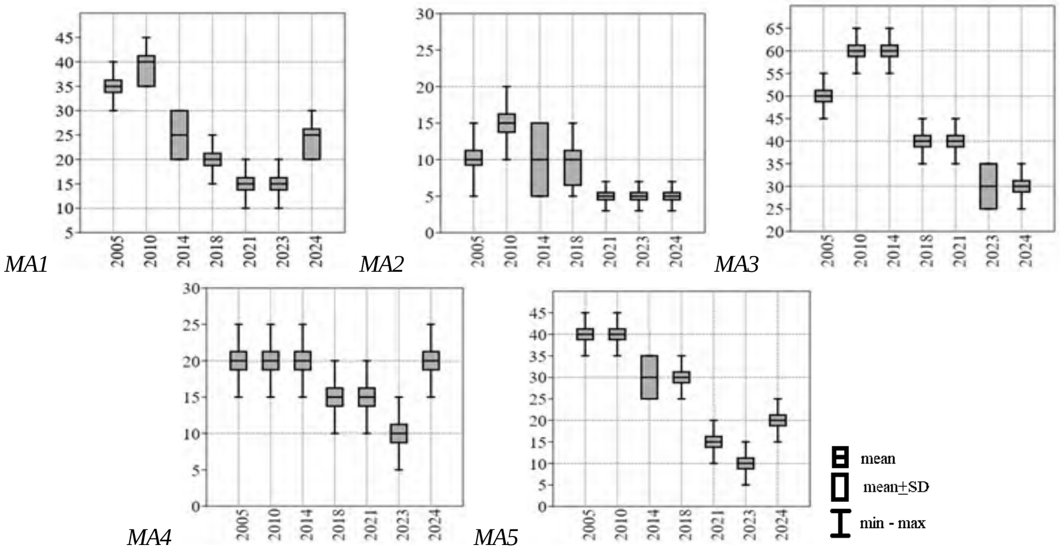

Fig. 4. Box-and-whisker plot of variability of projective cover of *Convallaria majalis* in monitoring areas 1–5 for the period 2005–2024: abscissa is year of resources research 2005, 2010, 2014, 2018, 2021, 2023 and 2024, ordinate is the projective cover of *Convallaria majalis* (%), MA 1–5 is the monitoring areas 1–5, SD – standard deviation

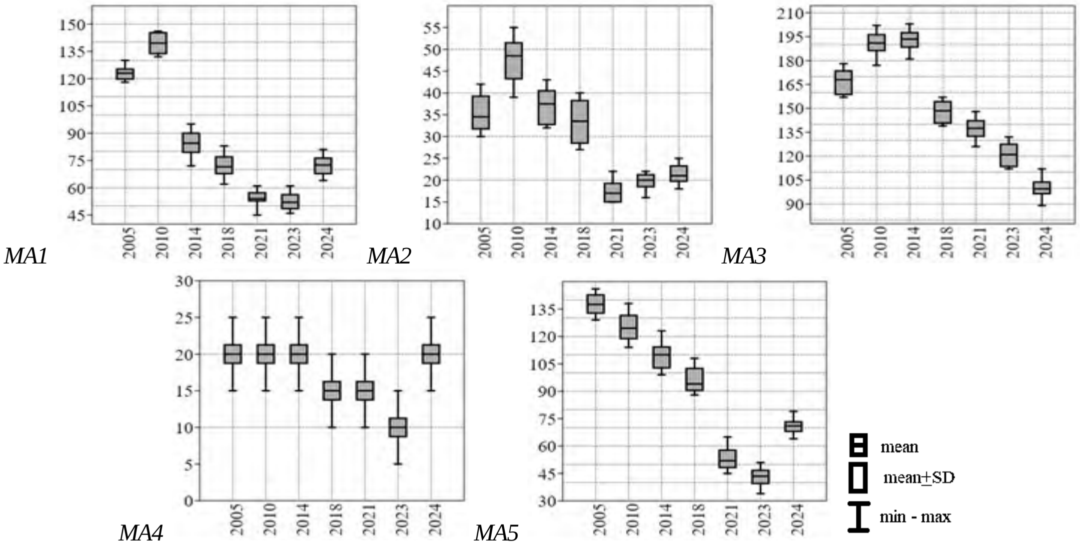

Fig. 5. Box-and-whisker plot of variability of density of *Convallaria majalis* partial shoots in monitoring areas 1–5 for the period 2005–2024: abscissa is year of resources research 2005, 2010, 2014, 2018, 2021, 2023 and 2024, ordinate is the density of *Convallaria majalis* partial shoots (pcs./m^2), MA 1–5 is the monitoring areas 1–5, SD – standard deviation

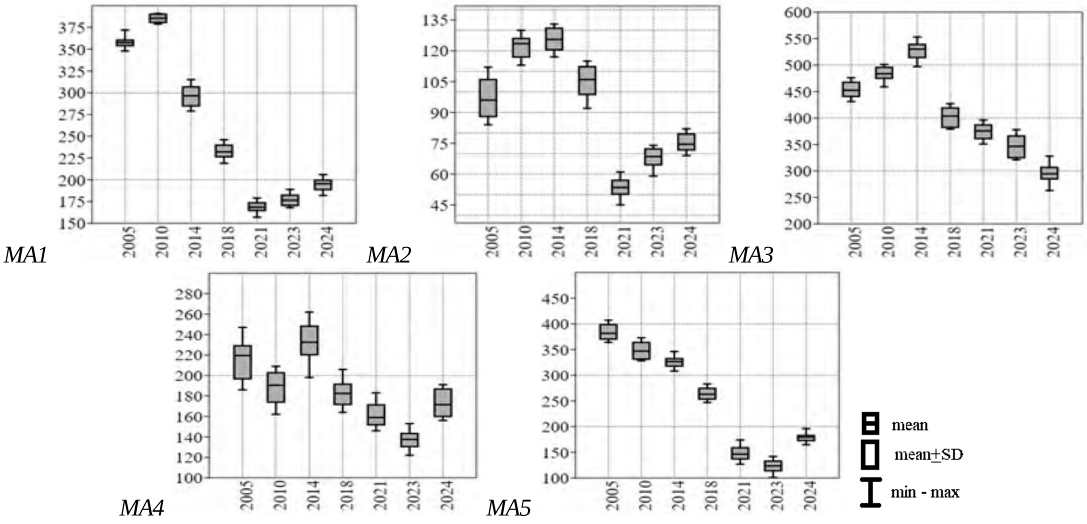

Fig. 6. Box-and-whisker plot of variability of density of raw material stock of *Convallaria majalis* (g/m^2) in monitoring areas 1–5 for the period 2005–2024: abscissa is year of resources research 2005, 2010, 2014, 2018, 2021, 2023 and 2024, ordinate is the density of raw material stock of *Convallaria majalis* (g/m^2), MA 1–5 is the monitoring areas 1–5, SD – standard deviation

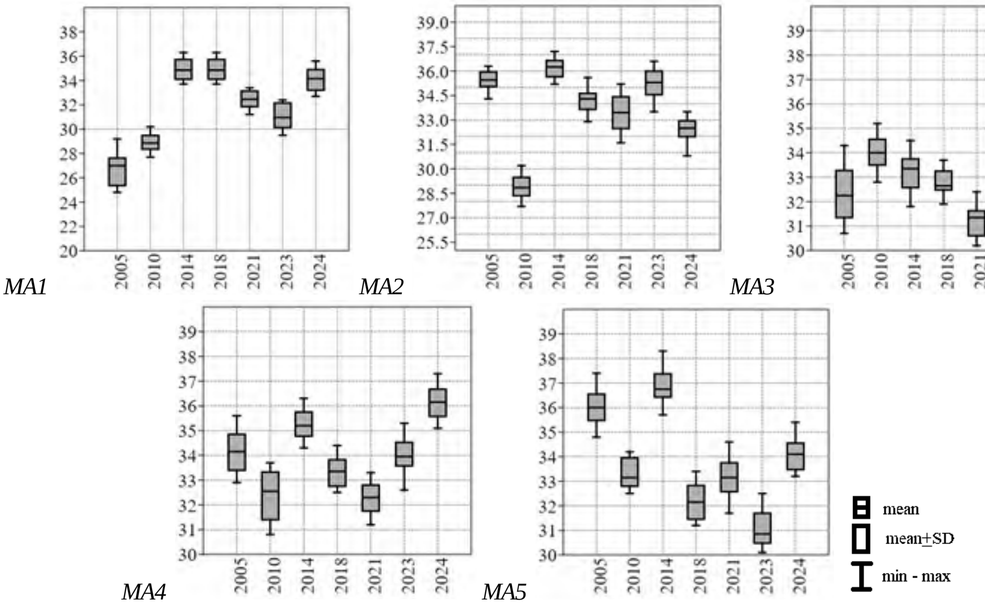

Fig. 7. Box-and-whisker plot of variability of plant height of *Convallaria majalis* (cm) in monitoring areas 1–5 for the period 2005–2024: abscissa is year of resources research 2005, 2010, 2014, 2018, 2021, 2023 and 2024, ordinate is the plant height of *Convallaria majalis* (cm), MA 1–5 is the monitoring areas 1–5, SD – standard deviation

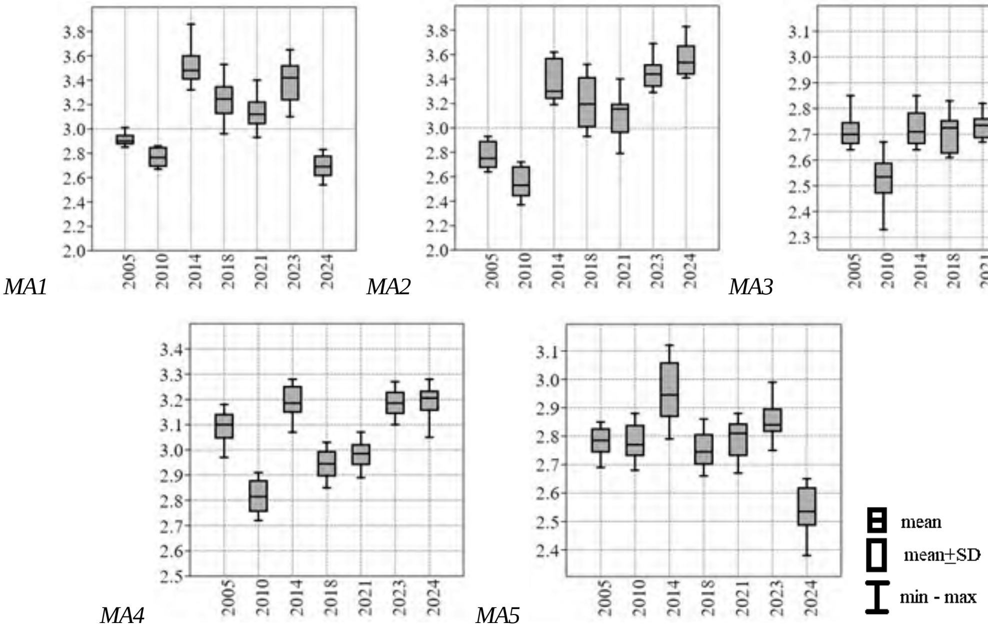

Fig. 8. Box-and-whisker plot of variability of shoot weight of *Convallaria majalis* (g) in monitoring areas 1–5 for the period 2005–2024: abscissa is year of resources research 2005, 2010, 2014, 2018, 2021, 2023 and 2024, ordinate is the shoot weight of *Convallaria majalis* (g); MA 1–5 is the monitoring areas 1–5, SD – standard deviation

Meanwhile, the average height of plants (Fig. 7) and the average weight of shoots (Fig. 8) on some MA decreased slightly (MA 2, 5 and MA 1, 5, respectively), and on others MA the values of these indicators increased during the observation period. The increase in average plant height and average shoot weight in some MA can be explained by a decrease in projective cover and shoot density; the number of plants is smaller, but they are better developed (larger).

According to meteorological data for the monitoring period (2005–2024), there is a gradual decrease in annual precipitation and an increase in the annual sum of mean monthly temperatures in the study region, which indirectly limits the resource capabilities of the populations of this species. At the same time, a similar trend is observed in April–June, the period of active growth and development of *C. majalis* (Figs. 2, 3). Additionally, there is an increase in the unevenness of precipitation, with periods of drought alternating with heavy rainfall. During the study, correlation analysis was performed, and the results reflect the relationships between resource indicators (projective cover, average plant height, shoot density, raw material density, and average weight of one shoot) and meteorological data (precipitation and sum of mean monthly temperatures) in both the current and previous years. The complete correlation matrices between the studied indicators of *C. majalis* plants from various sites are provided in Tables 3–7.

For MA 1 (Table 2), the relationship is statistically significant at the $P < 0.05$ level for $|r| > 0.36$. A pronounced positive relationship was found between the average plant height and the amount of precipitation during the period from April to June in the current ($r = 0.88$) and previous ($r = 0.45$) years. Meanwhile, the sum of the average monthly temperatures from the previous year shows negative correlations with resource characteristics, particularly with the density of raw material stock ($r = –0.67$) and the average weight of the shoot ($r = –0.51$). Projective cover generally does not reveal significant relationships with meteorological factors, showing only weak negative correlations.

Correlation coefficients are considered significant for MA 2 (Table 3), when |r| > 0.41 (P < 0.05). A significant positive effect of precipitation on the average shoot weight was found (r = 0.70 for April–June of the current year; r = 0.67 for the amount of precipitation for the previous year). However, temperature factors, particularly the sum of average monthly temperatures for the previous year, negatively affect all studied indicators, with the most considerable impact on average plant height (r = –0.70). Additionally, precipitation for April–June of the previous year is inversely related to projected cover (r = –0.60) and shoot density (r = –0.58).

For MA 3 (Table 4) the relationship is statistically significant at the P < 0.05 level for |r| > 0.56. The most pronounced negative correlations in this matrix are the relationships between the sum of average monthly temperatures for the current year and shoot density (r = –0.76), projective cover (r = –0.71), and raw material stock density (r = –0.74). These results indicate the inhibitory effect of high temperatures on plants. Interestingly, the average shoot weight, on the contrary, is positively correlated with this temperature factor (r = 0.78), which may suggest a specific physiological and biochemical adaptation. Precipitation primarily affects the shoot weight, whereas other indicators remain insensitive.

Table 2
Correlation between resource and meteorological data, MA 1

Resource indicator meteorological data	Projective cover	Average plant height	Shoot density	Raw material stock density	Average shoot weight
The amount of precipitation for April–June of the current year	–0.20	0.88*	–0.33	–0.21	0.34
The amount of precipitation for April–June of the previous year	–0.25	0.45*	–0.35	–0.40*	–0.15
The amount of precipitation for the current year	–0.06	0.27	–0.14	–0.24	–0.20
The amount of precipitation for the previous year	–0.32	0.83*	–0.42*	–0.26	0.43*
The sum of average monthly temperatures for April–June of the current year	0.43*	0.03	0.39*	0.29	–0.50*
The sum of average monthly temperatures for the current year	–0.16	0.67*	–0.31	–0.44*	–0.31
The sum of average monthly temperatures for the previous year	–0.35	0.52*	–0.48*	–0.67*	–0.51*

Note: starring with an asterisk, correlation coefficients are considered significant (P < 0.05).

Table 3
Correlation between resource and meteorological data, MA 2

Resource indicator meteorological data	Projective cover	Average plant height	Shoot density	Raw material stock density	Average shoot weight
The amount of precipitation for April–June of the current year	–0.36	0.51*	–0.21	0.09	0.70*
The amount of precipitation	–0.60*	–0.32	–0.58*	–0.52*	0.47*
The amount of precipitation for the current year	–0.15	0.20	–0.11	–0.17	0.03
The amount of precipitation for the previous year	–0.34	0.39	–0.23	0.09	0.67*
The sum of average monthly temperatures for April–June of the current year	0.29	–0.47*	0.28	0.34	0.10
The sum of average monthly temperatures for the current year	–0.56*	–0.25	–0.50*	–0.38	0.71*
The sum of average monthly temperatures for the previous year	–0.58*	–0.70*	–0.61*	–0.53*	0.61*

Note: starring with an asterisk, correlation coefficients are considered significant (P < 0.05).

Table 4
Correlation between resource and meteorological data, MA 3

Resource indicator meteorological data	Projective cover	Average plant height	Shoot density	Raw material stock density	Average shoot weight
The amount of precipitation for April–June of the current year	–0.09	0.18	–0.14	–0.01	0.64*
The amount of precipitation for April–June of the previous year	–0.22	–0.23	–0.35	–0.32	0.43
The amount of precipitation for the current year	–0.44	0.57*	–0.41	–0.40	0.41
The amount of precipitation for the previous year	–0.01	–0.19	–0.05	0.08	0.51
The sum of average monthly temperatures for April–June of the current year	–0.13	0.29	–0.15	–0.20	–0.02
The sum of average monthly temperatures for the current year	–0.71*	0.71*	–0.76*	–0.74*	0.78*
The sum of average monthly temperatures for the previous year	–0.59*	0.11	–0.67*	–0.69*	0.51

Note: starring with an asterisk, correlation coefficients are considered significant (P < 0.05).

Correlation coefficients are considered significant for MA 4 (Table 5) when |r| > 0.48 (P < 0.05). A positive effect of precipitation on average plant height (r = 0.90) and shoot weight (r = 0.90) is observed during the period from April to June of the current year. Temperature indicators demonstrate inverse relationships with shoot density (r = –0.69) and raw material stock density (r = –0.57). Overall, it was found that moisture has a more positive impact on the studied characteristics compared to temperature.

For MA 5 (Table 6) the relationship is statistically significant at the P < 0.05 level for |r| > 0.21. The strongest negative correlations were found between the temperature indicators of the previous year and all biometric characteristics, particularly with the density of raw materials stock (r = –0.77). Precipitation for the same period also shows inverse relationships, most notably with projective cover (r = –0.57). Current meteorological factors (temperature and precipitation) have a relatively weak or insignificant effect on plant parameters.

Table 5
Correlation between resource and meteorological data, MA 4

Resource indicator meteorological data	Projective cover	Average plant height	Shoot density	Raw material stock density	Average shoot weight
The amount of precipitation for April–June of the current year	0.23	0.90*	0.10	0.37	0.90*
The amount of precipitation for April–June of the previous year	0.08	0.34	–0.29	–0.17	0.36
The amount of precipitation for the current year	–0.17	0.36	–0.33	–0.27	0.35
The amount of precipitation for the previous year	0.27	0.71*	0.25	0.49	0.75*
The sum of average monthly temperatures for April–June of the current year	0.15	0.10	0.03	–0.08	–0.34
The sum of average monthly temperatures for the current year	–0.26	0.70*	–0.69*	–0.57*	0.50*
The sum of average monthly temperatures for the previous year	–0.21	0.28	–0.60*	–0.58*	0.10

Note: starring with asterisk, correlation coefficients are considered significant (P < 0.05).

Table 6
Correlation between resource and meteorological data, MA 5

Resource indicator meteorological data	Projective cover	Average plant height	Shoot density	Raw material stock density	Average shoot weight
The amount of precipitation for April–June of the current year	–0.18	0.58*	–0.05	–0.03	0.05
The amount of precipitation for April–June of the previous year	–0.57*	0.18	–0.54*	–0.53*	–0.19
The amount of precipitation for the current year	–0.02	–0.20	0.01	–0.03	–0.32*
The amount of precipitation for the previous year	–0.12	0.67*	0.09	0.03	0.10
The sum of average monthly temperatures for April–June of the current year	0.21	–0.33*	0.11	0.05	–0.56*
The sum of average monthly temperatures for the current year	–0.62*	–0.39*	–0.62*	–0.66*	–0.55*
The sum of average monthly temperatures for the previous year	–0.68*	–0.41*	–0.74*	–0.77*	–0.54*

Note: starring with asterisk, correlation coefficients are considered significant (P < 0.05).

Thus, the analysis results indicate a close relationship between the hydrothermal conditions of the vegetation period and the resource indicators of plants. The most pronounced effect is the positive impact of precipitation on the average height of plants and the mass of shoots, which is supported by the high correlation coefficients established for plants from the MA2, MA3, and especially MA 4. This effect can be interpreted as an adaptive response of plants to water deficit.

At the same time, temperature indicators, especially the mean annual values of the previous year, show a stable negative effect on the density of shoots and raw materials. This effect signifies cumulative heat stress, which adversely affects the parameters of the spatial and biomass structure of communities. Overall, the results support the hypothesis that deferred meteorological factors(precipitation and temperatures of the previous year) significantly influence biometric characteristics, not less than the conditions of the current vegetation period.

To improve the statistical interpretation of the correlations obtained between resource and biometric parameters of *C. majalis* and meteorological factors, we calculated 95% confidence intervals (CI) for all correlation coefficients with an absolute value greater than 0.6 using Fisher's z-transformation. The resulting intervals provide insight into the reliability and variability of the correlation estimates, particularly given the relatively small sample size (n = 7). The highest values of correlation coefficients and their 95% confidence intervals (CI) for monitoring areas are presented in Table 7. The correlation coefficients of only some variable pairs (resource indicator ~ meteorological factor) showed confidence intervals that did not include zero, indicating higher reliability. A strong correlation was observed between the average height of the plants and the amount of precipitation during April and May of the current year. Additionally, a moderate relationship was found between the number of partial shoots and the amount of precipitation at the beginning of the growing season. Conversely, a moderately negative correlation was identified between the density of raw material reserves and the sum of average monthly temperatures from the previous year. This suggests that the temperature regime does not significantly affect the resource availability of lily of the valley coenopopulations, which are protected by other species within the community.

The dynamics of morphometric and weight indicators of lily of the valley in individual monitoring areas varied during the years of observation. Overall, there is a consistent trend of declining resource significance for this species in the studied area.

Table 7
Highest values of correlation coefficients and their 95% confidence intervals (CI) for monitoring areas

Monitoring area	Variable pair (resource ~ meteorological indicator)	Correlation coefficient (r)	95% confidence intervals (CI)	Interpretation reliability
MA 1	Average plant height ~ the amount of precipitation for April–June of the current year	0.88	[0.37; 0.98]	high
MA 2	Average shoot weight ~ the amount of precipitation for April–June of the current year	0.70	[–0.11; 0.95]	doubtful (CI includes zero)
MA 3	Average shoot weight ~ the sum of average monthly temperatures for the current year	0.78	[0.07; 0.97]	sufficient
MA 4	Average plant height ~ the amount of precipitation for April–June of the current year	0.90	[0.45; 0.99]	very high
MA 5	Raw material stock density ~ the sum of average monthly temperatures for the previous year	–0.77	[–0.96; –0.04]	sufficient

Note: CI (confidence interval) shows the limits within which the true value of the correlation coefficient (r) is 95% likely to lie; if the CI includes zero, then the relationship may be statistically insignificant despite the high r.

Discussion

The threat of climate change's impacts on plant diversity is among the most discussed topics in scientific ecological research. Researchers study plant populations' responses to changes in moisture, light, and temperature regimes using various methods and techniques, including controlled field experiments, modeling, forecasting, and analyzing correlations between meteorological factors and changes in plant state (Mina et al., 2018; Vidhya et al., 2022).

The reaction of plant species to factors such as prolonged drought and temperature contrasts during the vegetation period is shaped by the ecological and cenotic plasticity of their cenopopulations (Ram, 2024; El-Beltagi et al., 2025). Disruption of the ecological balance of these ecosystems causes changes in the structure of the phytocenosis due to the suppression of stress-sensitive species' development, a decrease in productivity, and the growth rate of their cenopopulations (Kózak et al., 2021). The death of trees results in changes to the species composition of all layers of the forest phytocenosis. This transformation occurs as climate change compounds the effects of human activities over time (Pardi et al., 2021). It is known that changes in tree crown density significantly alter competition between herbaceous and shrub species (Kovalenko et al., 2023). Our study confirmed the same effect on *C. majalis* cenopopulations with an increase in the participation of shrub species in the phytocenosis. Increased heterogeneity of habitat conditions, caused by changes in the structure of the phytocenosis and variability of meteorological factors during the year, is a leading indicator of the dynamics of the structure of the grass layer in the studied forest communities. At the same time, species with weak adaptive properties gradually disappear from the phytocenosis, as was observed in our study with *Iris aphylla* subsp. *hungarica*, *Lilium martagon* and *Primula veris.*

At the same time, species with active life strategies or greater stress resistance are developing in communities such as *Chelidonium majus* and *Urtica dioica*. In some areas, an active expansion of *Euonymus europaea* and *Sambucus nigra* has been noted. These species fulfill various phytocenotic roles, including reducing biodiversity, influencing indicator species composition, and altering forest succession. They can compete with native species and exert trophic effects, disrupting the stability (Liebhold et al., 2017). In our studies, these species certainly exacerbated the stress on *C. majalis* cenopopulations due to a lack of moisture and temperature contrasts during the summer. While the structure of the forest phytocenosis underwent minor changes during the observation period, the resource importance of *C. majalis* decreased significantly. This may indicate irreversible destructive changes in its cenopopulations in the future, caused by a combination of climatic, anthropogenic, and coenotic influences.

The morphometric characteristics of partial shoots of *C. majalis* showed insignificant changes during the study period. However, there were significant negative changes in both shoot density and the amount of raw material per unit area. This indicates that environmental stress factors, particularly the lack of moisture during the growing season, could affect the viability of plants.

Conclusions

It was found that the structure of the phytocenosis of communities dominated by *Quercus robur* has undergone significant changes over the 20 years of observation. The species composition and the density of the tree layer have changed most noticeably, which may indicate a high sensitivity of trees primarily to variations in the moisture regime. At the same time, the presence of understory species, such as *Euonymus europaea*, *Sambucus nigra*, and *Crataegus* spp., has increased, suggesting the establishment of optimal conditions for their growth due to reduced competition from trees. In the herbaceous layer, the presence of species with a broad ecological amplitude and their inherent adaptive properties to changing environmental conditions, such as vegetative reproduction and the ability to survive under limited ecological factors, has increased.

Convallaria majalis populations are characterized by moderate adaptive properties to changing ecological and coenological conditions of their habitats. However, sharp fluctuations in moisture negatively affect their vitality and resource significance. Morphometric and weight indicators of *C. majalis* demonstrate a significant dependence on changes in climatic conditions, particularly the precipitation regime, and to a lesser extent, temperature fluctuations, which emphasize the vulnerability of this species to environmental stressors. Considering climate change trends, we can predict a decrease in the area distribution and resource potential of *C. majalis* in Ukraine.

It is anticipated that the decline of populations of herbaceous species in forest phytocenoses, such as lily of the valley, due to their weak adaptive capacity, primarily stemming from moisture deficiency during the vegetation period, may soon lead to fragmentation of their range, depletion of natural resources, and disappearance from many localities.

The results obtained lay the foundation for future research and the creation of strategies for adapting and preserving plant communities in the face of climate change.

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