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The impact of climatic parameters in Belgrade on the Indigo Himalayan species from the subtropical biome

Original Article

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Abstract:

Understanding the impact of climatic parameters on vegetation is significant for understanding the potential of urban green spaces, which play a crucial role in the ecological protection of cities and adaptation to climate change, particularly in regulating ecosystem services. In future climatic conditions, exotic species must be taken into account for ecosystem preservation. Therefore, for the first time, this study documents the differential attributes and phenology of *Indigofera heterantha* Wall. ex Brandis in Belgrade, thus increasing the floral diversity of Serbia. Through an integrative approach combining phenological and climatic data with biometric characteristics, indicators for the management and sustainability of Indigo Himalayan were identified, based on research conducted in 2024. The findings contribute to understanding urban biodiversity and strategies for adapting new exotics in Belgrade. However, further research is necessary to predict the impact of climate change on Indigo Himalayan.

Key words:
floristic list, exotic vegetation, biodiversity, phenology, morphology, landscape architecture, urban green spaces

Apstrakt:

Efekti klimatskih promena u Beogradu na vrstu Indigo Himalayan iz suptropskog bioma

Poznavanje uticaja klimatskih parametara na vegetaciju je značajno za razumevanje potencijala urbanih zelenih površina koje imaju ključnu ulogu u ekološkoj zaštiti gradova i prilagođavanju klimatskim promenama, posebno u regulisanju usluga ekosistema. U budućim klimatskim uslovima u cilju očuvanja ekosistema moraju se uzeti u obzir egzotične vrste. Stoga su u radu prvi put dokumentovani diferencijalni atributi i fenologija *Indigofera heterantha* Wall. ex Brandis u Beogradu, čime je povećan diverzitet flore Srbije. Integrativnim pristupom fenološkim i klimatskim podacima i biometrijskim osobinama, na osnovu istraživanja sprovedenih tokom 2024. godine, utvrdjeni su pokazatelji za upravljanje i održivost Indigo Himalayan. Nalazi doprinose razumevanju urbanog biodiverziteta i strategija adaptacije nove egzote u Beogradu. Ipak, neophodna su dalja istraživanja za predikciju uticaja klimatskih promena na Indigo Himalayan.

Ključne reči:
floristički spisak, egzotična vegetacija, biodiverzitet, fenologija, morfologija, pejzažna arhitektura

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Introduction

Studies of floristic diversity help assess the plant wealth and potential values of a specific region and create floristic lists (Shaheen et al., 2016). Life forms are indicators of micro and macroclimates, which result from plant adaptations, and understanding their phenology is the most reliable bioindicator, as well as a source of knowledge about periodic biological events influenced by environmental conditions (Ziter et al., 2019; Čukanović et al., 2024). Changes in the spring phenological key events of woody plants have been documented in research (Bertin, 2008; Petrov et al., 2024) and are more consistent in direction and magnitude than changes in summer and autumn phenophases (Zheng et al., 2016; Ocokoljić et al., 2023). Zheng et al. (2016) and Ocokoljić et al. (2023) analysed the bud burst, first flowering, full flowering, end of flowering, formation of the first leaf, full leafing, re-flowering, the beginning of leaf colour change, autumn colouration, the beginning of leaf fall, and the end of leaf fall in nine and twelve

woody taxa, respectively. The onset of spring and summer phenophases was recorded earlier, while autumn and winter phenophases occurred later compared to previous studies, showing significant correlations with air temperatures and accumulated heat sums.

Climate change can affect bud dormancy and cold resistance, which is important for the adaptation of woody plants and their survival during winter in the conditions of a moderately continental climate (Lang et al., 1987). Therefore, air temperatures are fundamental for regulating plant dormancy. In most woody plants of the temperate zone, growth cessation and bud dormancy are induced by short photoperiods in autumn, while low temperatures are required for breaking dormancy (Cosmulescu & Ionescu, 2018; Ocokoljić et al., 2024). Projected and current global warming in Europe is a focus due to the detrimental impact of mild winters and high autumn temperatures on woody plants. Concern is heightened for native species, as well as for non-native species, including the exotic *Indigofera heterantha* Wall. ex Brandis (First published in *Forest Fl. N.W. India*: 135, 1874), native to the subtropical biome from Afghanistan to Tibet and the Himalayas (FOP, 2025; POWO, 2025).

Faced with incomplete knowledge of the effects of climate change and the impact of global warming on the growth, development, and phenology of Indigo Himalayan in Belgrade's public green spaces, a study was conducted to determine the impact of seasonal air temperatures during summer and autumn on phenological processes. The study also aimed to assess the impact of climate challenges on the cessation of growth, extension of the growing season, new growth, secondary flowering, and the morphological attributes of the newly identified exotic species in Serbia. Additionally, the aim of the work was to promote the application of phenological data in landscape architectural compositions to optimise maintenance costs, plant material selection for appropriate locations and purposes, considering that woody taxa are vital elements in these compositions.

Materials and Methods

Study area

In the territory of Belgrade, a network of phenological stations was established over an area of 450 km² for the purposes of previous studies. In accordance with the recommendations of WMO (2009) and FHZ (2013), the observation sites are representative of the broader surroundings based on land type, terrain appearance and position, aspect, slope, and coverage of the urban and suburban zones. Through *in situ* phenomonitoring, within the established phenological network, *Indigofera heterantha* Wall. ex Brandis was first identified during spring 2024 in the Čukarica municipality, on Banovo Brdo, in a public green space.

The research area is a plaza where an individual of Indigo Himalayan, newly planted in a parterre composition, is georeferenced with coordinates 44°47'01.22"N and 20°25'03.62"E, at an altitude of 112 m, with a northeastern orientation (NE aspect) and a terrain slope of 1.64° (level to gently sloping terrain). The soil is of the anthropogenised Luvic Chernozem type (Anjos et al., 2015).

Climatic data

Data from the Republic Hydrometeorological Institute of Serbia (RHMZ) (https://www.hidmet.gov.rs/ciril/meteorologija/klimatologija_godisnjaci.php and https://www.ogimet.com/synopsc.phtml.en, accessed on 14 February 2025) from the Main Meteorological Station (MMS) Surčin (ϕ44º47'54.44"N and λ20º27'53.35"E, altitude 99 m) were used due to the similarity of environmental conditions. For the purposes of the study, time series of monthly and seasonal mean maximum and minimum air temperatures and precipitation were formed for the reference period (1991-2020) and the period 1991-2024, as well as daily maximum and minimum air temperature assessments for 2024, according to the respective percentiles.

Real–time field observations

After reconnaissance during spring 2024, phenological observations for Indigo Himalayan were recorded daily until January 2025, using the BBCH scale (Meier, 1997: 19 - First leaves fully expanded, 39 - Shoots about 90% of final length, 60 - Beginning of flowering (about 10% of flowers open), 65 - Full flowering (open at least 50% of flowers, first petal folling), 69 - End of flowering (all petals follen), 87 - Fruit ripe for picking, 91 - Shoot growth completed (terminal bud developed; foliage still fully green), 95 - Leaves discolour (50% of leaves discoloured) i 97 - All leaves fallen.

During the full flowering phase and the development of fully matured leaves in 2024, samples of 10 fully developed compound leaves and 5 inflorescences were taken, and the length and width of the compound leaf, the number of leaflets per leaf, the length and width of the leaflets, the length and width of the inflorescences, the number of flowers per inflorescence, and the maximum diameter of individual flowers were determined. The leaves and inflorescences were taken from the lower third of the southern side of the canopy. The samples were herbarium-processed, and then the morphometric

characteristics were determined using the UTHSCSA Image Tool, except for the flower diameter, which was measured with electronic calipers before herbarium processing. The abundance of the yield was assessed according to Stilinović (1985) using the Kaper scale from 0 to 5, where 0 – no yield (0% branches with fruits); 1 – very small yield (<20%); 2 – small yield (>20−<40%); 3 – moderate yield (>40−<60%); 4 – abundant yield (>60−<90%); and 5 – maximum yield (>90%). Fruits were collected immediately after ripening in October, and their length and width were measured with high-precision (±0.001 mm) electronic calipers. The number of seeds in the fruits was also determined. The colour of the leaves, flowers, and fruits was defined using the RGB (Red/Green/Blue) colour system.

Statistical analysis

To determine the significance of trends in climate data series, the non-parametric Mann-Kendall test was used, and to quantify the magnitude of the identified trends in the climatic time series, the Sen's slope method was applied. Growing Degree Days (GDD) for each of the key phenophases were determined using the method of Lalić et al. (2021). Relationships between air temperatures, primary and secondary flowering were analysed using the Spearman Rank test and regression. For the analysis of phenological changes, climate data and field observations were combined. Phenological responses of Indigo Himalayan, even in the first year, were variable in relation to literature reports, so adequate non-parametric methods were applied in accordance with the complexity of climatic events. For the analysis of morphological, quantitative data of Indigo Himalayan, descriptive statistics and the Spearman Rank test were used. Data processing was performed using the XLSTAT 2020 and Past 4.11 software packages.

Results and discussion

Chronology of climate data

On a monthly and annual basis, the average air temperatures, average maximum air temperatures, average minimum air temperatures, and total precipitation sums were calculated for the reference period (1991-2020), the period 2021-2023, and 2024 for the main meteorological station Surčin (**Tab. 1**).

The results are in line with the predictions (IPCC, 2019) that global warming will reach 1.5 °C between 2030 and 2052. However, when comparing the period 2021-2023 to the reference period, it is observed that the average temperatures have already exceeded the stated value (2.6 °C), which is consistent with the findings that greater warming than the global average has been observed in many regions and that higher values are found over land (IPCC, 2019).

Spearman's correlation coefficients were determined, with a probability of $p<0.05$ for the period 1991-2024, for average monthly maximum and minimum temperatures (0.979), average monthly maximum temperatures and total precipitation (0.706), and average monthly minimum temperatures and total precipitation (0.790). Very strong positive correlations between average monthly maximum and minimum temperatures, as well as between average monthly minimum temperatures and total precipitation, were statistically significant and indicate their consistently increasing relationship. The correlation between average monthly maximum temperatures and total precipitation is moderate and positive. The results of the Mann-Kendall and Sen's slope tests for the parameters for which Spearman's correlation coefficients (ρ) were determined are summarized in **Tab. 2**.

A significant increase in average monthly maximum temperatures was recorded in April, July, August, and December, in average monthly minimum air temperatures in February and from June to December, while a significant increase in monthly precipitation sums was observed only in May. Other trends were not statistically significant (**Tab. 2**). The findings of the study are consistent with the reports of WMO (2021).

Impacts of warming seasons on phenology

The required accumulated heat sum for the phenological phases of Indigo Himalayan during summer (**Fig. 1a**) was 1354.3 °C - 19BBCH (First leaves fully expanded), 2119.7 °C - 60BBCH (Beginning of flowering), 2481.3 °C - 65BBCH (Full flowering), and 2797.23 °C - 39BBCH (Shoots about 90% of final length). For the phenological phases during autumn (**Fig. 1b**), it was 3162.3 °C - 91BBCH (Shoot growth completed), 3262.7 °C - 69BBCH (End of flowering), 3348.8 °C – 19/2BBCH (First leaves fully expanded), 3532.4 °C – 39/2BBCH (Shoots about 90% of final length), 3575.1 °C – 60/2BBCH (Beginning of flowering), 3621.0 °C - 87BBCH (Fruit ripe for picking), 3729.5 °C – 65/2BBCH (Full flowering), and 3856.0 °C – 69/2BBCH. The 97BBCH phase - All leaves fallen was recorded at the end of December on the first shoot growth, without the leaf discoloration phase (95BBCH). Secondary growth completely ceased on December 25th following two extremely rainy days, during which a total of 32.4mm of precipitation was recorded, including 14cm of snow (RHMZ). The determined accumulated heat sums are consistent with those of ornamental taxa that flower in the summer and had secondary flowering during autumn 2022 in Belgrade

Table 1. Climatic variables for the reference period 1991-2020, 2021-2023, 2024 and deviations from the norm for temperatures and precipitations (%) for the Surčin weather station based on hourly and daily data (source RHMZ)

Mean air temperature (°C)													
Months period	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	
Tmean 1991/2020	1	3	7.5	12.9	17.6	21.4	23.2	23.2	18	12.8	7.4	2.2	**12.5**
Tmean 2021/2023	3.6	5.3	7.3	10.8	17.9	22.9	25.4	23.8	19.3	14.3	8.7	5.3	**13.7**
Tmean 2024	2.9	10.1	11.6	15.7	18.6	24.7	26.8	27.4	19.9	14.4	5.7	3.2	**15.1**
Deviation Tmean 2024 from normality 1991-2020	1.9	7.1	4.1	2.8	1	3.3	3.6	4.2	1.9	1.6	-1.7	1	**2.6**
Deviation Tmean 2024 from normality 2021-2023	-0.7	4.8	4.3	4.9	0.7	1.8	1.4	3.6	0.6	0.1	-3	-2.1	**1.4**
Mean maximum air temperature (°C)													
Tmean 1991/2020	4.5	7.4	12.9	18.4	23.2	26.9	29	29.3	24.1	18.5	11.9	5.5	**17.6**
Tmean 2021/2023	6.9	10.5	12.7	16	23.3	28.3	31.3	29.8	25.4	20.1	12.8	9.1	**18.8**
Tmean 2024	7.1	15.5	17.2	21.6	23.7	29.9	32.2	33.6	25.9	20.3	10.4	5.9	**20.3**
Deviation Tmean 2024 from normality 1991-2020	2.6	8.1	4.3	3.2	0.5	3	3.2	4.3	1.8	1.8	-1.5	0.4	**2.7**
Deviation Tmean 2024 from normality 2021-2023	0.2	5	4.5	5.6	0.4	1.6	0.9	3.8	0.5	0.2	-2.4	-3.2	**1.5**
Mean minimum air temperature (°C)													
Tmean 1991/2020	-2.3	-1	2.6	7.1	11.8	15.4	16.8	16.9	12.6	7.9	3.6	-0.9	**7.5**
Tmean 2021/2023	0.7	0.8	2	5.6	12.2	16.6	18.8	17.8	13.9	9.3	5.1	1.9	**8.7**
Tmean 2024	-0.8	5.2	6.3	9.3	13.6	18.4	20.1	19.8	14.1	9.3	1.4	0.7	**9.8**
Deviation Tmean 2024 from normality 1991-2020	1.5	6.2	3.7	2.2	1.8	3	3.3	2.9	1.5	1.4	-2.2	1.6	**2.3**
Deviation Tmean 2024 from normality 2021-2023	-1.5	4.4	4.3	3.7	1.4	1.8	1.3	2	0.2	0	-3.7	-1.2	**1.1**
Total and mean amounts of precipitation (mm)													
Period	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**∑**
Tmean 1991/2020	42.4	34	41.7	47.4	68.1	80.1	58.2	54	56	50.7	45.5	48.3	**626.4**
Tmean 2021/2023	48	35.6	26.8	59.2	60	57.5	65.4	51.9	72.7	39.9	103.4	75.4	**695.9**

Tmean 2024	37.1	4.8	27.7	23.3	99.8	92.5	69.4	6.5	86.8	44	45.6	63.2	**600.7**
Deviation Tmean 2024 from normality 1991-2020	87.5	14.1	66.4	49.1	146.5	115.4	119.2	12	155	86.8	100.2	130.8	**95.9**
Deviation Tmean 2024 from normality 2021-2023	77.2	13.5	103.5	39.4	166.3	160.8	106.1	12.5	119.4	110.4	44.1	83.8	**86.3**

Table 2. Results of the Mann-Kendall trend and Sen's slope tests for average monthly maximum and minimum air temperatures and monthly precipitation sums for the period 1991-2024, based on data from MMS Surčin

Test month	Tmean max			Tmean min			Precipitation		
	Kendall's tau	*p*-value	Sen's slope	Kendall's tau	*p*-value	Sen's slope	Kendall's tau	*p*-value	Sen's slope
I	0.187	0.123	0.071	0.23	0.058	0.072	0.116	0.343	0.34
II	0.226	0.062	0.146	0.301	**0.013**	0.109	0.162	0.182	0.38
III	0.123	0.313	0.052	0.226	0.062	0.062	0.034	0.79	0.115
IV	0.243	**0.045***	0.075	0.116	0.343	0.029	-0.036	0.778	-0.163
V	-0.041	0.744	-0.013	0.166	0.173	0.032	0.252	**0.038***	1.011
VI	0.219	0.071	0.06	0.508	**<0.0001***	0.082	0.041	0.744	0.235
VII	0.294	**0.015***	0.072	0.514	**<0.0001***	0.076	-0.048	0.7	-0.283
VIII	0.255	**0.035***	0.085	0.469	**0.000***	0.074	-0.071	0.563	-0.331
IX	0.194	0.109	0.069	0.351	**0.004***	0.076	-0.023	0.859	-0.157
X	0.191	0.116	0.068	0.266	**0.028***	0.055	-0.037	0.767	-0.164
XI	0.169	0.163	0.06	0.244	**0.044***	0.073	-0.009	0.953	-0.007
XII	0.339	**0.005***	0.141	0.369	**0.002***	0.103	0.002	1	0.008

*As the computed *p*-value is greater than the significance level 0.05, one cannot reject the null hypothesis H_0. H_0: There is no trend in the series

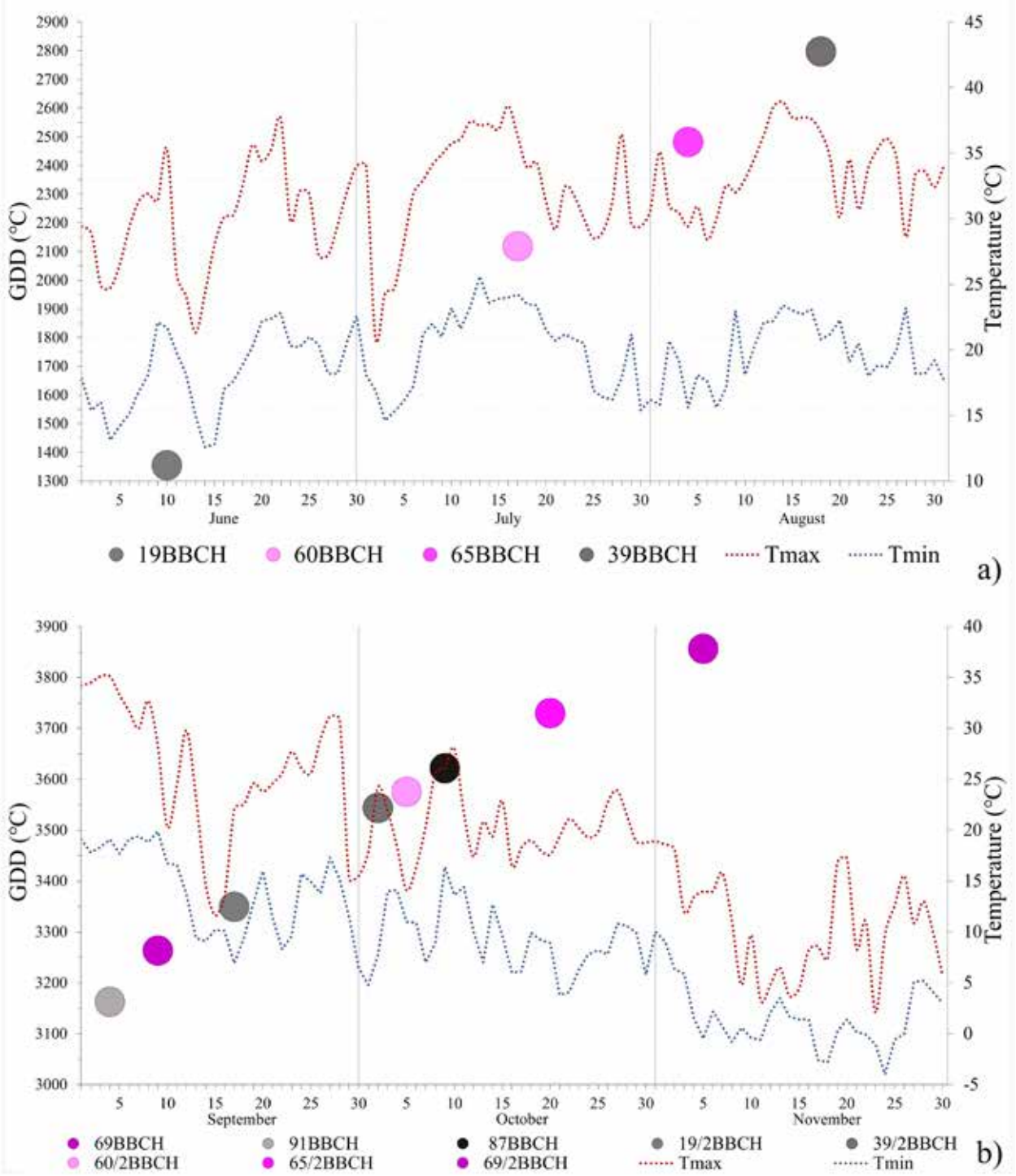

Fig. 1. Phenogram of Indigo Himalayan in Belgrade during 2024: a) 19BBCH (First leaves fully expanded), 39BBCH (Shoots about 90% of final length), 60BBCH (Beginning of flowering), 65BBCH (Full flowering) and b) 69BBCH (End of flowering), 87BBCH (Fruit ripe for picking), 91BBCH (Shoot growth completed), 19/2BBCH (Second first leaves fully expanded), 39/2BBCH (Second shoots about 90% of final length), 60/2BBCH (Second beginning of flowering), 65/2BBCH (Second full flowering) and 3856.0 °C – 69/2BBCH (Second end of flowering)

(Ocokoljić et al., 2023). The studied elements of the phenological patterns suggest that Indigo Himalayan, due to its habitus and flowering, possesses high ornamental value at the end of summer and during autumn, which is why introduced species are important in the selection of plants for urban landscape design, as noted by Khamraeva et al. (2024).

According to Wu & Raven (2010), Indigo

Himalayan flowers during the period of May-June, while according to Brickell & Kindersley (2008), flowering occurs during the summer, which is consistent with the Pl@ntNet database (GBIF, 2025) for the Northern Hemisphere and our research. However, secondary flowering, which followed on the new shoot growth (on average 27 cm) during September and October 2024 in Belgrade (**Fig. 2**), has not been previously recorded. The results require a comparative analysis of phenological and climatic data, considering the findings of Büntgen et al. (2022) that the onset and longer duration of the growing season reflect the local climate.

Fig. 2. a) Autumn shoots with secondary leafing (8 October 2024), and **b)** secondary flowering (with silver linden in the background in the leaf discoloration phase, 16 October 2024) of Indigo Himalayan on the square in Belgrade

Considering that regular irrigation of the newly planted species was recorded during phenomonitoring, and that Indigo Himalayan is a drought-resistant species (AGM, 2017), it is evident that air temperatures, primarily the maximum and minimum temperatures during summer and autumn, have the most significant impact on multiple phenological responses, as this is a species from the subtropical biome. Therefore, to adequately understand the phenological responses to climate change, seasonal warming trends (summer and autumn) were determined based on data from MMS Surčin. The growth of T mean for summer 2024 (June-August) was 3.7 °C, for autumn (September-November) 0.6 °C, Tmeanmax 3.5 °C and 0.7 °C, and Tmeanmin 3.0 °C and 0.3 °C. The significance of trends in mean maximum and minimum air temperatures according to the Sen's slope test is shown in **Fig. 3**.

A significant increase in mean maximum temperatures was observed only for July and August (summer). In contrast, Tmeanmin shows significant increasing trends for both summer and autumn. The primary flowering lasted for 47 days, and after 28 days and a heatwave in September, secondary flowering began and lasted for 36 days until the first frost day (minimum temperature below 0 °C, RHMZ). Taking into account the aforementioned trends, and in order to assess the phenological responses based on daily maximum and minimum air temperatures, a regression analysis was conducted for primary and secondary flowering (**Fig. 4**).

A rising trend is evident for both variables during summer (**Fig. 4a** and **b**) after approximating the isolated data, i.e., determining the regression line. However, the increase in daily maximum and minimum air temperatures did not affect primary flowering, which is expected given the species' origin. During secondary flowering (**Fig. 4c** and **d**), the trend is decreasing for both variables, and the decline in minimum temperatures significantly

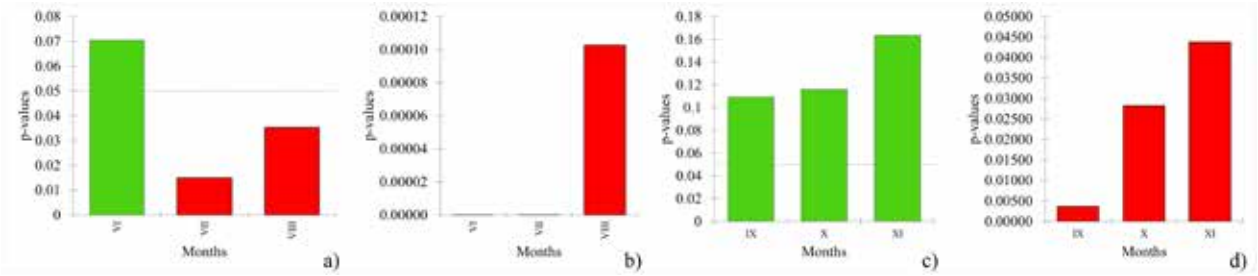

Fig. 3. Graphical representation of Sen's slope and *p*-value for seasonal mean monthly maximum and minimum air temperatures for summer (a and b) and autumn (c and d) for the period 1991-2024, based on data from MMS Surčin (values in red are slopes for statistically significant trends (p<0.05))

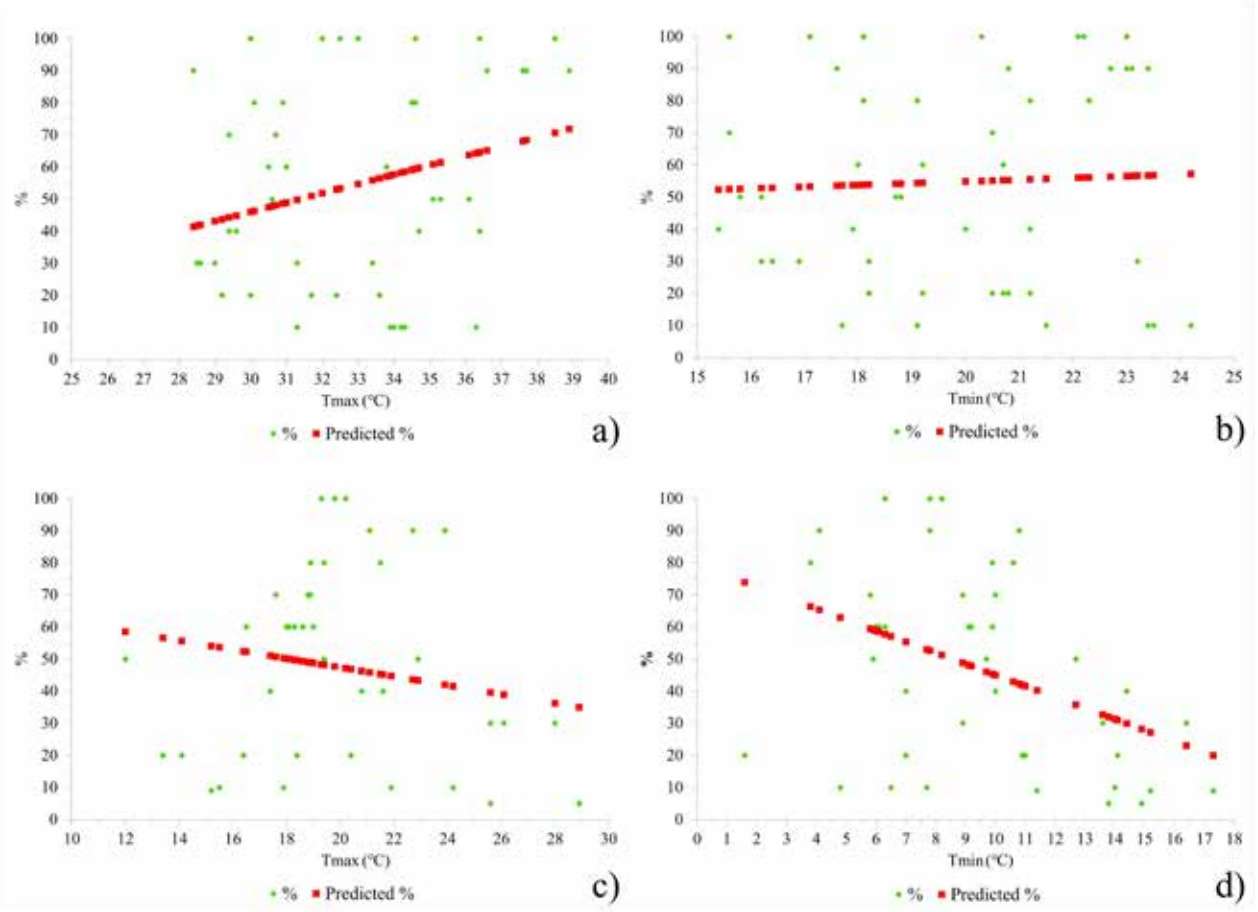

Fig. 4. Scatter plots and predictions of the impact of daily maximum and minimum air temperatures during the primary (**a** and **b**) and secondary (**c** and **d**) flowering periods of Indigo Himalayan in Belgrade

affected secondary flowering. Data analysis showed that for primary flowering of Indigo Himalayan, the daily maximum and minimum temperatures were in a ratio of 74.7%: with a maximum of 33.6 °C and a minimum of 19.6 °C; while for secondary flowering, in a ratio of 68.8%, the temperatures were 19.4 °C (max) and 8.3 °C (min). Statistical significance of the conclusions, at $p<0.0001$, is confirmed by the results of the regression ANOVA analysis (**Tab. 3**).

The research indicates that temperatures influence the trends of phenological phases in Indigo Himalayan in Belgrade, which is consistent with documented variations globally (Piao et al., 2019), in Europe (Menzel et al., 2020), and in Serbia (Čukanović et al., 2024, Petrov et al., 2024). The findings also align with the statements by Mack et al. (2000), suggesting that biological invaders thrive at the expense of the environment in natural areas, while exotic species in urban zones act as components of the landscape that improve environmental conditions. Considering that, according to Pérez–Ramos et al. (2019), the phenology of plants is influenced by climate change differently depending on location and taxa, and given that the growth or decline of temperatures influences Indigo Himalayan to varying degrees („a tolerant species down to -15 °C that fully regenerates the following year even after freezing to the ground", AGM, 2017), it is possible to predict its adaptability, sustainability, ornamental value, as well as its ecological stability and ecosystem services.

Morphometric studies of the leaf, floral structures and fruits

Indigo Himalayan is a deciduous shrub that can grow up to 3 meters in height (Wu & Raven 2010). In the studied location, by the end of 2024, it reached a height of 2.10 meters, with a long flowering period during the second half of summer (Brickell & Kindersley, 2008). Considering that there are fewer such taxa in Belgrade, and that the species was identified for the first time on a public green space, the study focused on the metric and morphological characteristics of the leaves, inflorescences, flowers, and fruits. The length of the leaves ranged from 16.5 cm to 26.8 cm, while the number of leaflets in the compound leaf ranged from 18 to 27. The length of the leaves reported in some earlier studies and

Table 3. ANOVA results for the impact of daily maximum and minimum air temperatures on the flowering of Indigo Himalayan in Belgrade, at a significance level of $p<0.0001$

Parameter	df	SS	MS	F	Significance F
Summer					
Tmax					
Regression	1	3390.892	3390.892	3.407603	0.071481
Residual	45	44779.32	995.096		
Total	46	48170.21			
Tmin					
Regression	1	89.08413	89.08413	0.083375	0.7741
Residual	45	48081.13	1068.47		
Total	46	48170.21			
Autumn					
Tmax					
Regression	1	1529.262	1529.262	1.641548	0.207679
Residual	39	36332.3	931.5974		
Total	40	37861.56			
Tmin					
Regression	1	6415.05	6415.05	7.955953	**0.00001**
Residual	39	31446.51	806.3208		
Total	40	37861.56			

research was considerably smaller than the findings in Belgrade, as Hammad et al. (2021) report a leaf length of 6 to 7 cm. The result for the number of leaflets is consistent with the FOP (2025), which notes that a compound leaf contains between 13 and 31 leaflets. However, this study also observed that the leaves were both even and odd-pinnate (50:50%), a feature that has not been previously recorded in the literature available to the authors. The standard deviations were low (0.88 and 1.01), as were the coefficients of variation (13.43 and 13.44), indicating low variability for both parameters. The length of the leaflets ranged from 25.0 mm to 42.9 mm, and the width ranged from 11.8 mm to 19.2 mm, which exceeds the ranges of 5 to 25 mm for length and 2 to 15 mm for width reported by Hammad et al. (2021) and FOP (2025). The standard deviations were low (1.76 and 0.87), but the coefficients of variation were high (15.58 and 17.19), indicating higher variability. The Spearman Rank correlation coefficient, with a probability of $p<0.05$, between the length and width of the leaflets confirmed a strong positive correlation (0.98788), indicating that as the length of the leaflets increases, so does their width, as well as a moderate positive correlation between leaf length and the number of leaflets (0.66061), meaning that as the leaf length increases, the number of leaflets in the compound leaf also increases. Other correlations were not significant. The upper side of the leaflets is dark green (RGB 49/76/21), and the underside is gray-green (RGB 125/149/117)

The size of the inflorescence and flowers, as well as their color, are of particular importance for flowering ornamental species. The study results highlight the inflorescence length, which ranged between 4.0 and 4.8 cm, the inflorescence width, which was 4 cm for all analyzed inflorescences, the number of flowers per inflorescence, ranging from 22 to 24, and the largest flower diameter, which ranged from 0.8 to 1.1 cm (**Fig. 5a** and **b**). The research findings for the inflorescence length align with the range of 4 to 8 cm reported by Hammad et al. (2021). The available literature does not provide any information on the number of flowers per inflorescence, the width of the inflorescence, or the largest diameter of individual flowers. The small variability is confirmed by the low values of standard deviation (0.56, 0.1, 1.41, and 0.21) and coefficients of variation (12.85, 0.6, and 6.14) for the first three parameters, while a higher variability is observed for the largest flower diameter with a coefficient of variation of 22.32. The Spearman Rank correlation coefficient, with a probability of $p<0.05$, between the inflorescence length and the number of flowers, the inflorescence length and the flower diameter, and the number of flowers per inflorescence and the flower diameter is positive and complete, which is adequately confirmed by the results of descriptive statistics. Other correlations were not significant. The visual aspect of the inflorescence and flower is shown in **Fig. 5a** and **b**. The outer side of the petals is in shades of pinkish-purple (RGB 177/108/129 to 168/93/116), while the inner side is a light lavender color (RGB 168/135/144) with a yellow-brown or skin-like spot (RGB 188/168/177).

The fruit yield was low (rating 1), and the seed production relative to the number of embryos was very low (9.09%). The fruits were elongated, linear pods in shades of brown ranging from RGB 100/70/46 to 86/64/50 (**Fig. 5c**). The length of the pods ranged from 3.7 to 6.2 cm, the largest pod width from 6.5

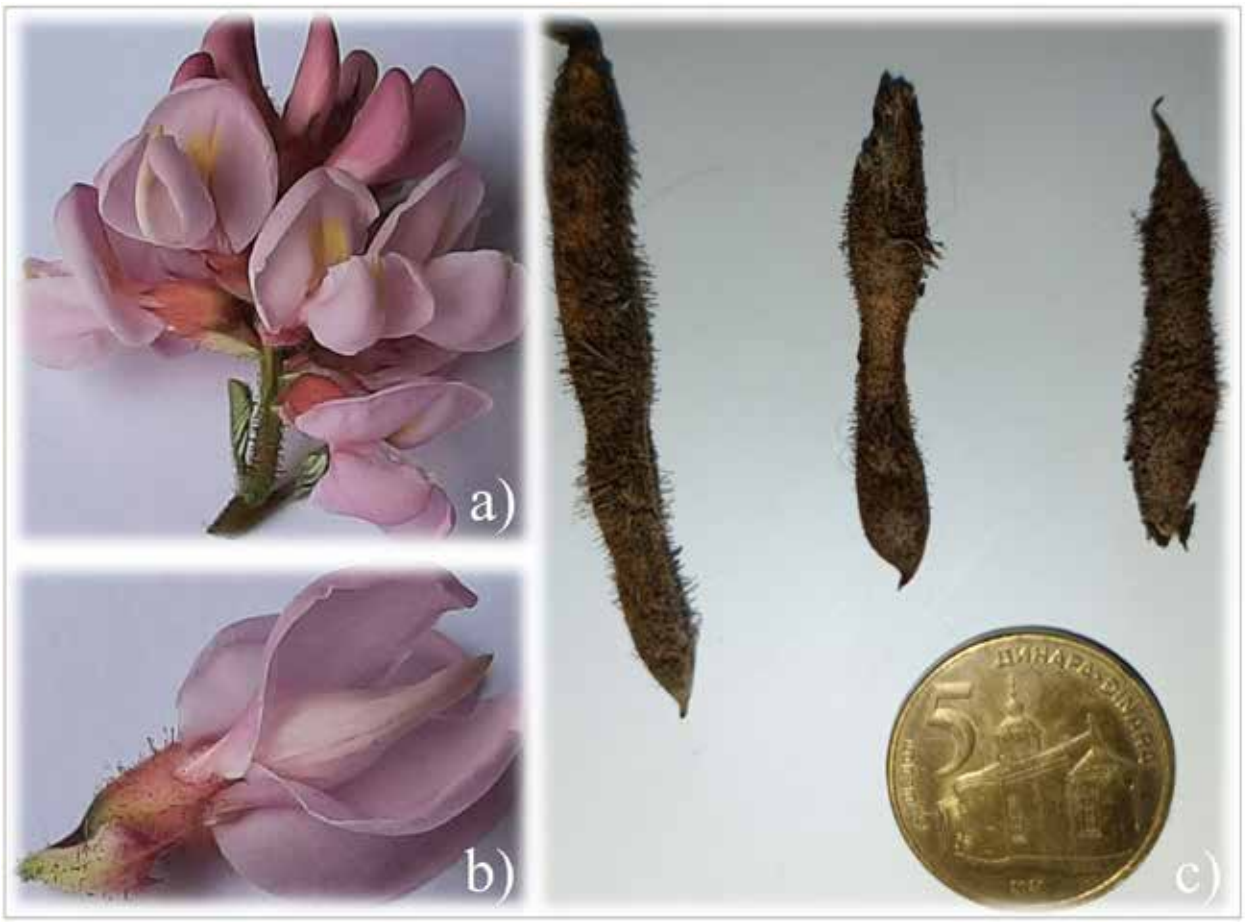

Fig. 5. Inflorescences **a)** and individual flower **b)** from the primary flowering (August 4, 2024) and **c)** mature fruits (October 16, 2024) of Indigo Himalayan in Belgrade

to 7 cm, and the number of seeds per pod ranged from 3 to 5. The length and width of the pods are in agreement with the findings of FOP (2025), and the seed count is consistent with the results of Wu & Raven (2010). The standard deviation was low (1.30, 0.29, and 1.5), but the coefficients of variation for the length of the pods and seed count were high (27.57 and 31.49), indicating their higher variability. An exception is the largest pod width, where the coefficient of variation is low (4.33). The Spearman Rank correlation coefficients, with a probability of $p<0.05$, were not statistically significant for the analyzed fruit parameters.

The pioneering research conducted in Belgrade during 2024 and January 2025 contributes to the conservation of Indigo Himalayan as a flowering ornamental species from extinction, as predicted by Bachman et al. (2024), although there are no predictions regarding the species' threat status (IUCN, 2025). To make a reliable estimate of the future global vegetation development, it is essential to identify vegetation responses to climate change. In this sense, this quantitative review and analysis indicate acclimatization as an ecological process that enables the spread of Indigo Himalayan beyond the subtropical biome as a response to global warming.

Conclusion

The study provides basic information on the effects of climate change on the phenology and morphology of the leaves, flowers, and fruits of Indigo Himalayan in an urban landscape, under the conditions of a moderately continental climate. However, it is essential that research continues in order to quantify all attributes of this new exotic species in Serbia. Future studies should focus on the aesthetics, functionality, identity, and ecology of urban landscapes where Indigo Himalayan serves as an element in landscape architectural compositions. This is because exotic species have advantages over native ones in terms of ecological performance and adaptive capacity, with the obligation to investigate their potential invasiveness when introduced to new habitats. The importance of further research confirms the concerns of researchers and designers regarding the potential negative impacts of exotic species and the advantages of using native species, which has

led to the recommendation by scientists that native vegetation should be prioritized over exotic species, even in urban green spaces.

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