Invasion of Tree-of-Heaven (*Ailanthus altissima* (Mill) Swingle) in Urban and Rural Areas of Vukovar-Syrmia County

Invazija žljezdastoga pajasena (*Ailanthus altissima* (Mill) Swingle) u urbanim i ruralnim područjima Vukovarsko-srijemske županije

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INVASION OF TREE-OF-HEAVEN (*Ailanthus altissima* (MILL) SWINGLE) IN URBAN AND RURAL AREAS OF VUKOVAR-SYRMIA COUNTY

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SUMMARY

This study focuses on the distribution and impact of the invasive species tree-of-heaven (Ailanthus altissima (Mill) Swingle) in the easternmost county of the Republic of Croatia. The research was conducted from May to September 2022 and 2023, utilizing the systematic random sampling method. The presence of tree-of-heaven was recorded in both rural and urban environments, where only the number of trees having a medium tree trunk diameter at breast height (DBH) of 10-20 cm and a small DBH of 5-10 cm was significantly higher in rural compared to urban sites. The negative effects of the tree-of-heaven population are due to its vigorous clonal growth (biological characteristics; $p < 0.001$) and dense monoculture stands, resulting in decreased plant species richness and native species diversity (ecological impact; $p < 0.001$. The harmful effects of invasion depend on the site where plants grow. Still, serious damage, based on significant factor loadings (eigenvalue >1), was recorded not only on environmental but also on functional, safety, and aesthetic aspects, causing economic loss and mechanical damage.

Keywords: invasive tree, rural environment, urban environment, risk assessment, harmfulness, Vukovar-Syrmia County

INTRODUCTION

Tree-of-heaven (*Ailanthus altissima* (Mill) Swingle) is a deciduous species, native to north and central China, Taiwan, and North Korea, but nowadays, it can be found all over the world, except Antarctica (Kowarik and Sämuel, 2007; Boer, 2012). This dioecious species belongs to the Simaroubaceae family and can grow up to 30 m. Female trees are insect-pollinated, and seed dispersal is predominantly by wind, and even in water (Kowarik and Sämuel, 2008). Besides its dispersal by seeds (generative), tree-of-heaven is capable of reproducing vegetatively by producing root and stem sprouts (Kowarik and Sämuel, 2007), and has a fast height growth rate in its first years, reaching up to 2 m per year (Steppe et al., 2015).

This species was introduced to European cities as an ornamental tree and soon became invasive due to its very intensive and spontaneous spread, as well as its ability to adapt to various types of soil and water regimes (Richardson et al., 2000; Čarni et al., 2017). Tree-of-heaven is very common in urban environments, due to its adaptation to heat, drought, air pollution, and various soil properties (Demeter et al., 2021). In rural environments, it occupies roadsides, fencerows, and woodland edges, and frequent transportation corridors (McAvoy et al., 2012; Planchuelo et al., 2016). Once established, it can quickly create a dense stand because of fast growth and root-sucker production (Pan and Bassuk, 1986).

Besides the negative influence on ecosystem services and biodiversity, the tree-of-heaven also provides numerous benefits to humans, particularly in mitigating environmental and economic costs by utilization in bioenergy and biofuels, and wood products (Terzopoulou et al., 2023). Eradication is problematic since this species has a high regenerative capacity (Sladonja et al., 2015). Since

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the cities are invasion hotspots for this species, Kowarik et al (2021) investigated citizens' perspectives, and respondents generally accept the tree-of-heaven as a part of the urban environment, but at the same time, support management efforts where it could be problematic.

This research is established to understand the distribution patterns of this invasive tree species and to evaluate the impact of invasion in rural and urban environments in Vukovar-Syrmia County. By understanding the ecological and socio-economic impact, it is possible to integrate various management options to prevent further severe natural disturbance.

MATERIAL AND METHODS

Study area: Vukovar-Syrmia County is located in the northeastern part of the Republic of Croatia, partly in eastern Slavonia and partly in western Syrmia, between the Danube and Sava rivers. This easternmost county borders: Osijek-Baranja County to the northwest, Serbia to the east, Bosnia and Herzegovina to the south, and Brod-Posavina County to the west (Figure 1). With its 2448 $km^{2,}$ it represents 4.3% of the State's territory. Arable land, vineyards, orchards, and forests dominate the structure of the county's land.

This area experiences a temperate continental climate with warm and sunny summers and cold winters. The average annual temperature is around 11 °C, while the average annual precipitation ranges from 650 mm in the east to 800 mm in the west of the county.

Sample design: The study was conducted from May to September 2022. and 2023. using a systematic random sampling method (Kent and Coker, 1992). Samples were taken at regular intervals in a grid system created by regularly shaped squares of 5 km x 5 km, having 98 squares in total county area. In each square where the tree-of-heaven was noticed (N=46), both in rural and urban areas, a subsequent sampling unit of a 100 m^2 plot (10m x 10m) was established for further analysis.

Datasets were extracted from each plot and include:

A) quantitative: i) plant cover (%); ii) species richness; iii) tree diameter

B) qualitative: iv) a risk assessment; v) a questionnaire of plant harmfulness

A plant cover was estimated according to the 7-degree Braun-Blanquet scale (Braun-Blanquet, 1964). Braun-Blanquet indices of species cover (r, +, 1, 2, 3, 4, and 5) were transformed to percentage cover with the following intervals: 0-1, 1-5, 5-10, 10-25, 25-50, 50-75, and 75-100%. Species richness represents the number of tree-of-heaven per sampling unit (plot), and the tree trunk diameter at breast height (DBH) was measured at breast height and divided into several classes: large >20 cm, medium 10-20 cm, small 5-10 cm, and very small < 5 cm.

Figure 1. Study area: map of Vukovar-Syrmia County.

Slika 1. Područje istraživanja: karta Vukovarsko-srijemske županije.

Risk assessment analysis was used to classify this plant invasion according to its biological characteristics, ecological amplitude, impact, and difficulty of control using a standardized form according to "Ranking Invasive Exotic Plant Species in Virginia" (Anonymous, 2001).

Finally, plant-harmless questionnaires were conducted on every plot to understand the impact of tree of heaven invasion, comprising a total of 51 questions grouped into functional, environmental, health and safety, and aesthetic aspects (modified from Casella and Vurro, 2013; questions regarding archeological sites and skin irritation were excluded).

Statistical analysis: The statistical analysis was conducted using IBM SPSS Statistics (Version 22) for the quantitative dataset, where mean comparisons of plant cover, species richness, and tree diameter in rural and urban sampling sites were made using a two-sample t-test (H0: rural = urban). The data from the questionnaire survey were used to compare and contrast sites and risk assessment categories. They were analyzed with the direct analysis, Canonical Correspondence Analysis (CCA) in CANOCO 5 for Windows using a global permutation test at 1000 iterations (Ter Braak and Smilauer, 2012), after the first performed detrended correspondence analysis (DCA) showed a rather long gradient on the first canonical axis (4.685 SD units in the compositional turnover). The forward selection of explanatory variables was tested with Monte-Carlo permutations, followed by the determination of the statistical significance for each explanatory variable singly (simple effect) and for additional explained variance (conditional effect). Factor analysis with principal component extraction was used to identify factors for understanding the harmfulness of the tree-of-heaven invasion in the investigated territory. A Kaiser (Eigenvalue) Criterion with rule 1 was applied to keep the factors with eigenvalues greater than 1 and neglect those that do not. To select the most appropriate factor solutions, varimax or orthogonal factor rotation is applied. This analysis was done with IBM SPSS Statistics (Version 22).

A) B)

Figure 2. Invasion of tree-of-heaven in: A) rural, and B) urban areas of Vukovar-Syrmia County.

Slika 2. Invazija žljezdastoga pajasena na A) ruralnim i B) urbanim područjima Vukovarsko-srijemske županija.

Source/Izvor: foto E. Štefanić.

RESULTS AND DISCUSSION

The tree-of-heaven was found across the Vukovar-Syrmia county, both in rural (Figure 2A) and urban (Figure 2B) environments. During the study period, 29 sites were evident in urban areas and 17 sites in rural areas. Plants were found to be patchily distributed, and infested areas were found on both public and private properties.

Among all sites, tree-of-heaven cover (Braun-Blanquet, 1964) ranged from 0.5 (+) to 37.5% (3) in rural sites, and from 0.5 (+) to 62.5% (4) in urban sites. Species richness ranged from individual specimens to very dense sites, featuring both adult and juvenile individuals. T-test for mean plant cover and density per plot (10 m x 10 m) did not show significant differences between the rural and urban sites (Table 1).

Of the total recorded trees in urban areas, those with diameters more than 20 cm comprised 25 specimens (3.96%), while in rural sites, 27 large trees were recorded (9.9%). In both environments, very small individuals dominate with 95% in urban areas and 79% in rural areas. However, for the number of trees with medium DBH (10–20 cm) and small DBH (5–10 cm), the difference was significant (Table 1). The average number of trees with small DBH is higher in rural environments (1.71 ± 3.27) compared to urban environments (0.07 ± 0.26). The same is for the number of trees with medium DBH, where results showed that there were 1.59 (± 4.65) more individuals per sample unit compared to the mean number of plants in urban sites (0.14 ± 0.52).

Table 1. Summary variables for tree-of-heaven presence in rural and urban areas in Vukovar-Syrmia County

Tablica 1. Sažetak varijabala za prisustnost žljezdastoga pajasena u ruralnim i urbanim područjima Vukovarsko-srijemske županije

Tree-of-heaven / *Žljezdasti pajesen*	**Means (STD) sample units** / *Srednje vrijednosti (SD) jedinice uzorka*		**t-stat**	**P** £
	Rural	**Urban**		
Plant cover (%)	2 (10-25%)	3 (25-50%)	0.150	0.756
Species richness	15.94 (± 28.69)	21.80 (± 95.17)	0.234	0.523
Number of plants per site with dbh*				
Large > 20 cm	1.59 (± 4.65)	0.86 (± 2.63)	-0.679	0.176
Medium: 10 – 20 cm	1.59 (± 4.47)	0.14 (± 0.52)	-1.740	0.003
Small: 5 – 10 cm	1.71 (± 3.27)	0.07 (± 0.26)	-2.700	0.000
Very small: < 5 cm	11.06 (± 21.74)	21.07 (± 47.63)	0.415	0.391

*DBH = trunk diameter at breast height – *prsni promjer debla*

£ P = 0.01-0.05*; P=0.001-0.005**; P=0.0001-0.0005***

These findings are in line with many other published papers that confirmed the invasion of tree-of-heaven in urban and rural environments (Fotiadis et al., 2011; Casella and Vurro, 2013). However, with virtual street inventory in Istanbul, Ulus et al. (2021) found tree-of-heaven mostly in groups on historic walls, open areas, and abandoned regions, where of the total recorded trees dominated specimens with 10-20 cm DBH (38%), while juvenile plants (very small, < 5 cm DBH) dominated in this research. These results indicate that the invasion of the pajasena in our area is more recent than that described in Ulus et al. (2021) research, where trees with a medium trunk diameter at breast height dominate in their environment.

Negative effects of the tree-of-heaven population in urban and rural environments are due to the vigorous clonal growth and dense monoculture stands (Sladonja et al., 2015) as well as decreased levels of plant species richness and native species diversity (Brooks et al., 2021), which was also noticed in this research (Figure 3).

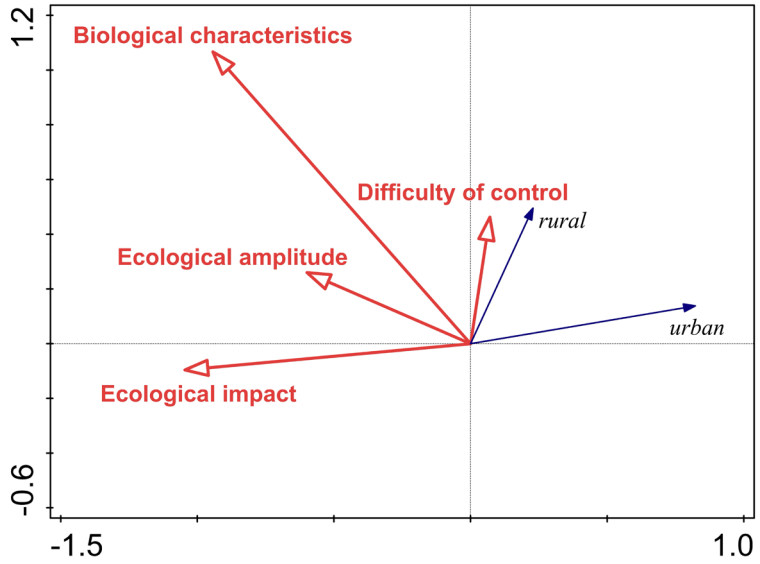

Figure 3. Canonical correspondence analysis (CCA) on Axis 1 and Axis 2 showing the relationship between the tree-of-heaven appearance and risk assessment categories for Vukovar-Syrmia County.

Grafikon 3. Kanonska korespodencijska analiza (CCA) na osi 1 i osi 2 koja prikazuje odnos između pojavnosti žljezdastoga pajasena i kategorija procjene rizika za Vukovarsko-srijemsku županiju.

Axis 1 (Figure 3) captured 44.46% of the variation in the dataset and was explained by longer vector length, significant biological characteristics, and ecological impact that influence the invasion of this species in Vukovar-Syrmia county. The second axis (Figure 3) explains an additional 25.35% of variation, confirming the significance of the ecological impact that the tree-of-heaven causes on this territory.

The results from the forward selection of the explanatory variables (Table 3) confirmed that most variance in the dataset, when examined as a simple (singly) effect, is influenced by biological characteristics of the tree-of-heaven and its ecological impact, particularly in the urban environment. However, the conditional effect, when tested in order of their inclusion in the model, indicated that only its biological and ecological characteristics are the main vectors of successful invasion. This confirmed invasive behaviors as described in many reports (Sladonja et al., 2015; Planchuelo et al., 2016), particularly on the newly disturbed areas (McAvoy et al., 2012).

Table 2. Results from canonical correspondence analysis

Tablica 2. Rezultati kanonske korespondencijske analize

Axis loadings / *Opterećenja osi*	**Axes** / *Osi*			
	1	2	3	4
Eigenvalues / *Svojstvene vrijednosti*	0.1478	0.0843	0.0744	0.0260
Pseudo-canonical correlation / *Pseudo-kanonička korelacija*	0.8800	0.7589	0.7955	0.6445
Explained fitted variation (cumulative) / *Objašnjena prilagođena varijanca (kumulativno)*	44.46	69.81	92.19	100.00

The negative effects of the tree-of-heaven have become an issue of global concern, and risk assessment for non-native species in many areas prioritizes this species for management options (Boer, 2012). Casella and Vurro (2013) observed thirty-five different types of damage caused by tree-of-heaven, mainly in urban districts, industrial areas, roads, railways, and airports.

Table 3. Results of forward selection of explanatory variables

Tablica 3. Rezultati unaprijednoga odabira objašnjavajućih varijabli

Variable / *Varijable*	**Simple effect** / *Jednostavni učinak*			**Variable** / *Varijable*	**Conditional effect** / *Uvjetni učinak*		
	Explains %	**Pseudo-F**	**P**		**Explains %**	**Pseudo-F**	**P**
Biol. characteristics	10.9	2.2	0.001	Biol. characteristics	10.9	2.2	0.001
Ecological impact	8.6	1.8	0.001	Ecological impact	6.9	1.3	0.001
Ecol. amplitude	7.7	1.7	0.086	-	-	-	-
Difficulty of control	1.1	1.4	0.198	-	-	-	-

In Vukovar-Syrmia County, the tree-of-heaven seriously harms urban infrastructure, particularly causing economic loss and mechanical damage. Factor analysis, performed on the plant harmfulness questionnaire (Casella and Vurro, 2013), extracted 10 significant factor loadings (Table 4). The first two factors explain a cumulative 40.704% of variance and were related to environmental degradation. The following eight factors each explained less than 10% variance and were related to functional, safety, and aesthetic types of damage.

Many researchers have reported the ecological and economic impact of this species (Motard et al., 2011; Ulus et al., 2021). In this research, as well as in Casella and Vurro's (2013) study, the lack of management of this species harms the environment.

CONCLUSION

Different levels of the tree-of-heaven invasion occur in both urban and rural areas of Vukovar-Syrmia County. Plants were found patchily distributed, from individual specimens to dense monocultural stands, with the only significant difference being more specimens per sampling area with medium dbh (10–20 cm) and small dbh (5–10 cm) in rural regions. Biological characteristics and ecological impact make this species very competitive compared to local flora due to significant production of vegetative root suckers, which allows it to form large monospecific stands. Where established, tree-of-heaven can also cause a potential risk for functional, safety, and aesthetic damages.

Table 4. Significant factor loadings of the rotated component matrix for the harmful effect of the tree-of-heaven invasion in Vukovar-Syrmia County

Tablica 4. Signifikantna faktorska opterećenja rotirane matrice za štetni učinak invazije pajasena u Vukovarsko-srijemskoj županiji

Significant Factor loadings / *Značajna faktorska opterećenja*	**Explanation** / *Objašnjenje*	**Extraction Sums of Squared Loadings** / *Značajna faktorska opterećenja*		
		Total	**% of variance**	**Cumulative %**
1	Change the structure of plant communities	12.428	26.443	26.443
2	Forming a dense monoculture	6.703	14.262	40.704
3	Difficulties with maintenance	4.708	10.017	50.721
4	Economic loss due to increased maintenance costs	4.368	9.293	60.014
5	Mechanical damage to water pipelines	3.270	6.957	66.971
6	Mechanical damage to bicycle lines	3.028	6.442	73.413
7	Mechanical damage to sidewalks	2.011	4.280	77.693
8	Aesthetic degradation	1.690	3.595	81.288
9	Hazards of the view reduction for drivers	1.404	2.986	84.274
10	Obscuring traffic signs	1.228	2.613	86.887

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INVAZIJA ŽLJEZDASTOGA PAJASENA (*Ailanthus altissima* (MILL) SWINGLE) U URBANIM I RURALNIM PODRUČJIMA VUKOVARSKO-SRIJEMSKE ŽUPANIJE

SAŽETAK

Ova studija analizira rasprostranjenost i utjecaj žljezdastoga pajesena (Ailanthus altissima (Mill) Swingle) u najistočnijoj županiji Republike Hrvatske. Istraživanje je provedeno od svibnja do rujna 2022. i 2023. godine metodom sustavnoga slučajnog uzorkovanja. Prisutnost ove invazivne vrste zabilježena je i u ruralnim, i u urbanim sredinama, u kojima je samo broj stabala srednjega prsnog promjera (10 – 20 cm) i maloga promjera (5 – 10 cm) bio značajno veći u ruralnim u usporedbi s urbanim područjima. Negativni učinci populacije pajesena posljedica su snažnoga klonskog rasta (biološke karakteristike; $p < 0.001$) i gustih monokulturnih sastojina, što uzrokuje smanjenu razinu bogatstva biljnih vrsta i raznolikosti autohtonih vrsta (ekološki utjecaj; $p < 0.001$). Štetni učinak uzrokovan invazijom ovisi o mjestu na kojem biljke rastu, ali ozbiljne štete temeljene na rezultatima faktorske analize (svojstvena vrijednost faktora >1) zabilježene su ne samo na okolišnom već i na funkcionalnome, sigurnosnom i estetskom aspektu, uzrokujući ekonomske gubitke i mehanička oštećenja.

Ključne riječi: žljezdasti pajasen, ruralna područja, urbana područja, analiza rizika, štetnost, Vukovarsko-srijemska županija

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