Scientific Papers. Series B, Horticulture. Vol. LXX, No. 1, 2026
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

EARLY-STAGE EVALUATION OF INVASIVE PLANT IMPACTS ON HISTORIC MONUMENTS: CASE STUDY OF BELLU CEMETERY

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Abstract

Urban cemeteries represent complex cultural landscapes where natural and anthropogenic factors interact, influencing both biodiversity and the preservation of built heritage. This preliminary study investigates the impact of invasive vegetation on the structural integrity and conservation status of historical monuments within Bellu Cemetery, Bucharest. Field observations and qualitative assessments were conducted to document invasive plant species, their distribution patterns, and the types of physical or biochemical deterioration observed on stone and metal monuments. Early findings indicate that woody species such as Ailanthus altissima exert mechanical stress through root penetration, while climbing taxa such as Parthenocissus quinquefolia accelerate surface decay and microclimatic changes that favour biodeterioration. The results highlight the need for integrated management strategies that balance ecological value with heritage conservation. This early-stage research will continue and contributes to the emerging field of biocultural heritage studies by providing baseline data for future quantitative analyses and restoration planning.

Key words: *Bellu Cemetery, biodeterioration, conservation, cultural heritage, historical monuments, invasive plant species.*

INTRODUCTION

Urban green spaces such as cemeteries represent unique socio-ecological systems where natural processes and cultural values intersect (Francis et al., 2011; Kowarik et al., 2016). As multifunctional landscapes, they simultaneously serve as habitats for diverse species and as repositories of collective memory, art, and architectural heritage (Linden et al., 2020). Within these environments, the presence of invasive plant species has emerged as a growing concern, not only for biodiversity management but also for the conservation of historical monuments and funerary structures (Davis et al., 2019). The interaction between invasive vegetation and built heritage introduces complex ecological and physicochemical processes that accelerate material decay and compromise the integrity of monuments (Caneva et al., 2008).

Invasive plants are characterized by rapid growth, high reproductive capacity, and adaptability to disturbed habitats - traits that make them successful colonizers in urban ecosystems (Richardson & Pyšek, 2012). In cemeteries, where maintenance regimes may fluctuate and microhabitats are varied, these species often establish and expand rapidly (Löki et al., 2019). Their physiological and morphological traits, such as deep root systems, climbing habits, and allelopathic interactions, can exert both mechanical and biochemical stress on monument materials (Warscheid & Braams, 2000). Mechanical stress arises from root penetration into cracks or joints, leading to bioexpansion and microfracturing, while biochemical stress results from organic acid exudation and moisture retention that enhance corrosion and biodeterioration (Caneva et al., 2008; Miller et al., 2020).

The degradation of stone, brick, and metal monuments by vegetation is well documented in conservation science (Caneva & Ceschin, 2009; Miller et al., 2020). Plants contribute to biodeterioration through a range of mechanisms including chemical alteration of substrates, microclimate modification, and facilitation of microbial colonization (Warscheid & Braams, 2000). These processes are amplified in the presence of invasive taxa whose growth dynamics differ markedly from native flora. Yet, despite increasing attention to plant-induced decay, the interdisciplinary dialogue between ecological research and heritage conservation remains limited (Lisci et al., 2003). Most studies address either the biological aspects of

invasiveness or the material science of deterioration, with few integrating both domains to provide a holistic understanding of how ecological succession influences heritage stability.

Certain plant communities possess significant naturalistic value and simultaneously contribute to the improvement of local microclimatic conditions (Zangari et al., 2023). Vegetation can play a dual role in heritage contexts: while some species offer protective and stabilizing effects, others pose severe threats to the conservation of historical structures (Motti et al., 2020, 2021b; Prieto et al., 2024). Higher plants, including invasive taxa, often colonize stone monuments, wall surfaces, and adjacent areas of historical sites. Their growth dynamics are influenced by human disturbance, microclimatic parameters such as temperature and humidity, and interactions with surrounding vegetation.

Increasing anthropogenic pressure in urban areas has often reduced biodiversity protection and altered the floristic composition of historical environments (Panitsa et al., 2022). Therefore, the primary objective of management interventions is not the complete eradication of vascular plants, but the regulation of vegetation growth to ecologically and aesthetically acceptable levels (Cozzolino et al., 2025). Such management should aim to evaluate the potential biodeterioration risks posed by vegetation and to develop preventive maintenance plans adapted to the site's ecological context.

Understanding the ecological role and mechanical impact of invasive plants within heritage contexts requires an integrative approach combining taxonomy, vegetation ecology, and conservation science. By comparing vegetation composition and structural patterns across one sector of Bellu Cemetery, this study aims to provide a preliminary assessment of how invasive flora contribute to monument deterioration and how their presence reflects the successional stage of the cemetery ecosystem.

MATERIALS AND METHODS

Popescu (2014) provides a comprehensive description of Bellu Cemetery in Bucharest that stands as a significant cultural landscape, reflecting the evolution of urban burial practices, funerary art, and national memory in Romania.

Until the mid-19th century, the dead of Bucharest were typically interred in churchyards or informal burial grounds within or at the margins of the city. In the early 1850s, new sanitary and urban planning concerns (including the risk of epidemics) motivated the municipal authorities to designate new cemetery grounds outside the densely populated centre. The estate owned by Baron Barbu Bellu (1825-1900) on Calea Șerban Vodă was chosen: he donated the land to the town in about 1853/1852. The landscaping and initial works commenced around 1852 under the direction of local authorities, including C. A. Rosetti. As the city expanded, and churchyard burials were gradually outlawed, many remains and family monuments were transferred to Bellu, increasing its prestige and spatial footprint. Over time, the cemetery expanded to cover around 28 hectares (or approximately 220,000 m²) and became home to a prodigious collection of funerary monuments, chapels, mausoleums, and sculptural works created by leading architects and artists of the era. The style mix in the funerary monuments spans Neo-Gothic, Art Deco, Neo-Romanian, and Beaux-Arts influences; the site is sometimes described as an "open-air museum" of funerary sculpture. Bellu became not merely a burial ground but a spatial archive of Romania's 19th- and 20th-century elite: writers, poets, scientists, politicians, and public figures. In recognition of its architectural and memorial value, it was included in the Association of Significant Cemeteries in Europe network and in the European Cemeteries Route. The cemetery's layout, monuments, and inscriptions function as tangible markers of collective memory and identity, linking the urban fabric of Bucharest with national heritage. Situated now within a largely built-up sector of Bucharest (Sector 4), the cemetery faces challenges typical of heritage sites: conservation of monuments, vegetation control, visitor management, and balancing its active role as a burial ground with its function as a heritage site. It continues to operate while being open to the public for walking, study, and contemplation.

The "Șerban Vodă Cemetery - Bellu" ensemble is listed in the List of Historical Monuments 2010 - Municipality of Bucharest under no. 22438, LMI code B-IV-a-B-20118.

First step in our study was to inventory the plant species from a sector of a cemetery, about 200 square meters, highlighting the status (native or alien) of the registered plant species, their frequency and distribution on Romanian territory, and their general distribution in the world, according to Ciocârlan (2009).

The weathering patterns, following recommendations by Caneva et al. (2023), were established through direct observation, photographic documentation, and microscopic observation using a Bresciani portable microscope.

We analyze the invasiveness stage of *Ailanthus altissima*, *Hedera helix,* and *Parthenocissus quinquefolia,* and we tried to identify their weathering patterns on the graves and the surrounding walls.

In addition, it was analysed the growth pattern and spreading ways of *Ailanthus altissima,* as the main invasive species inside the cemetery. *Ailanthus altissima* is a dioecious tree (male ♂ and female ♀ flowers on separate plants) and has the ability to reproduce both by seeds and by sprouts, thus allowing tree of heaven to spread and quickly dominate disturbed areas.

On transects, 2 m in width, starting from one female individual toward the other female individuals considered as sources of the offspring, we measured, for every offspring, the distance from the source (m), density (number of individuals), canopy surface (m^2), height (cm), trunk diameter (cm) [diameter at breast level – DBH. Also, we made observations regarding the offspring: young (no ♀ and ♂ differentiation), seedlings possibly emerging from root sprouts and from cut stems – based on height and leaf shape.

Using a GPS Garmin E-Tres Summit, we recorded the GPS coordinates of female individuals – mother source of new shoots (offspring).

For mature trees, we registered a wealth of fruiting (poorly - richly).

RESULTS AND DISCUSSIONS

From an ecological perspective, the colonization of cultural heritage sites by invasive flora reflects broader processes of urban succession and habitat transformation (Kowarik, 2011).

Cemeteries, particularly those established in the nineteenth century, like Bellu Cemetery in Bucharest, were designed as landscaped environments integrating ornamental vegetation with monumental architecture (Popescu, 2014). Over time, reduced maintenance, environmental changes, and species introductions have reshaped these landscapes, creating novel ecosystems that blur the boundaries between natural and artificial habitats (Francis et al., 2011). In this context, invasive woody species such as *Ailanthus altissima* (tree of heaven) are frequently documented as agents of ecological disturbance and structural degradation in heritage settings (Caneva et al., 2009; Papini et al., 2017).

The establishment and structure of plant communities depend on multiple factors, including spatial availability, soil characteristics, substrate disintegration, and both micro- and macroclimatic conditions. Persistent exposure to moisture, wind, and temperature fluctuations fosters the colonization of organisms that contribute to biodeterioration processes (Mascaro et al., 2021; Cozzolino et al., 2022). The vegetation surrounding a monument significantly influences the composition and diversity of local flora, thereby affecting colonization intensity.

For stone monuments, the potential of vascular plants to establish is closely related to the stone's chemical composition, degree of exposure, surface inclination, and prior interactions with other biodeteriorative agents (Cozzolino et al., 2025). Plants are considered deteriogenic agents because they induce erosion, cracking, structural instability, and material detachment through combined biophysical and biochemical mechanisms, which ultimately reduce the cohesion between mineral grains (Trotta et al., 2020; Mascaro et al., 2021). These processes involve both assimilatory mechanisms - through which plants extract nutrients from the substrate -and dissimilation, during which metabolic by-products react chemically with the stone matrix. Weathering often results from ion-exchange processes occurring at root tips, the action of colloidal particles along lyotropic gradients, or the release of root exudates that modify substrate pH (Elgohary et al., 2024). The mechanical pressure exerted by root expansion contributes further to damage, as the increasing root diameter and soil volume alteration lead to displacement and fragmentation of stone materials (Caneva et al., 2006). In addition to structural effects, vegetation growth can obstruct access to monuments, conceal

architectural features, and create an impression of neglect (Kanellou et al., 2017).

Abandonment or insufficient maintenance of monuments and historic sites frequently promotes the rapid colonization of invasive species (Caneva et al., 2023). Systematic risk assessment and related management measures are essential to prevent further structural damage. Fitzner (2004) proposed a general hazard index linking weathering processes to biological colonization, identifying 25 typologies of damage associated with biodeterioration. More recently, Caneva et al. (2023) defined a series of indicators describing hazards related to site conditions and weathering patterns produced by higher plants, including soiling, superficial erosion, discoloration, fracturing, detachment, and collapse.

The plant species inventoried in Bellu Cemetery in summer 2025 (Table 1) are distributed very frequently and frequently in from the steppe zone of Romania to the beech level, most of them being characteristic to the sylvo-steppe zone (forest steppe ecoregion) (EEA, 2019) to which Bucharest metropolitan belongs. The adventive (invasive, alien) plant species (Sandlund et al., 2001) found here find the optimum for their survival and spread.

Table 1. The plant species inventoried from a segment of the cemetery in summer 2025

Species	Frequency in Romania					Distribution in Romania								General distribution	Status
	very frequent	frequent	sporadic	raer	Very rare	steppe zone	Sylvo-steppe zone	oak forests zone	common oak level	beech level	boreal level (of spruce)	Subalpine level (of juniper)	alpine level (of alpine grasslands)		
Acer campestre L.	1					1	1	1	1					Europe and West Asia	
Acer negundo L.	1					1	1	1	1					North America	
Acer platanoides L.	1						1	1	1					Europe and West Asia	
Ailanthus altissima (Mill.) Swingle	1													China	adventive
Anisantha sterilis (L.) Nevski (syn. *Bromus sterilis* L.)		1				1	1	1	1	1				Eurasia (sub-Mediterranean)	
Aristolochia clematitis L.			1				1	1	1	1				Europe	
Ballota nigra L.		1				1	1	1	1	1				Europe	
Brachypodium sylvaticum (Huds.) Beauv.		1					1	1	1	1				Eurasia (sub-Mediterranean)	
Carex spicata Huds.		1				1	1	1	1	1	1			Circumpolar	
Celtis occidentalis L.														North America	adventive
Chelidonium majus L.		1				1	1	1	1	1				Eurasia	
Chenopodium album L.		1				1	1	1	1					Eurasia	
Cirsium arvense (L.) Scop.		1				1	1	1	1	1	1			Eurasia	
Convolvulus arvensis L.														Mediterranean	
Digitaria sanguinalis (L.) Scop.		1				1	1	1	1					Cosmopolite	
Erigeron canadensis L. (syn. *Conyza canadensis* (L.) Cronquist)	1					1	1	1	1	1				North America	adventive
Euphorbia sp. (*Chamaesyce* group)		1					1	1	1	1				North America	adventive
Fallopia dumetorum (L.) Holub.			1											Circumpolar	
Geum urbanum L.		1				1	1	1	1	1				Mediterranean- Circumpolar	
Hedera helix L.		1						1	1	1				Atlantic-Mediterranean	
Inula britannica L.		1				1	1	1	1					Eurasia	
Lactuca serriola L.		1				1	1	1	1					Eurasia	
Melissa officinalis L.			1					1	1	1				Mediterranean	cultivated
Oxalis stricta auct. non L. (syn. *Oxalis fontana* Bunge)			1											North America	adventive
Parthenocissus quinquefolia Planch.			1											North America	adventive
Pastinaca sativa L.		1					1	1	1	1				Eurasia (sub-Mediterranean)	
Phytolacca americana L.			1											North America	adventive
Plantago major L.		1				1	1	1	1	1	1			Eurasia	
Poa trivialis L.		1						1	1	1	1			Eurasia	
Polygonum aviculare L. agg.		1				1	1	1	1	1	1			Cosmopolite	
Portulaca oleracea L.		1				1	1	1	1					Cosmopolite	
Saponaria officinalis L.		1				1	1	1	1	1				Eurasia	
Sedum spp.				1										-	adventive
Setaria pumila (Poir.) Roem. et Schutt.	1					1	1	1	1	1				Cosmopolite	
Silene vulgaris (Moench) Garcke	1				1	1	1	1	1	1	1			Eurasia	pioneer
Solanum dulcamara L.		1				1	1	1	1	1				Eurasia	
Sonchus oleraceus L.		1				1	1	1	1	1				Cosmopolite	
Sorghum halepense (L.) Pers.		1				1	1	1						Mediterranean	
Verbascum blattaria L.		1				1	1	1	1					Euras. (sub-Mediterranean)	
Verbena officinalis L.		1				1	1	1	1	1				Cosmopolite	
Viola sp. (either *V. odorata* L. or *V. alba* Besser)		1				1	1	1	1	1				Atlantic-Mediterranean	

Tree of heaven (*Ailanthus altissima* (Mill.) Swingle) is recognized as one of the most invasive woody species in temperate regions worldwide (Motti et al., 2021c; Soler & Izquierdo, 2024a). Its ecological success is attributed to a combination of high reproductive capacity, efficient dispersal mechanisms, and remarkable adaptability to disturbed environments. The diameter at breast height (DBH) serves as a reliable indicator of seed productivity, with mature female trees capable of producing up to 300,000 seeds annually (Soler & Izquierdo, 2024b). The seeds are primarily dispersed by wind, although many remain attached to the canopy throughout the winter, facilitating extended dispersal periods.

The species exhibits both sexual and asexual modes of reproduction, enhancing its colonization potential. Wind dispersal typically allows seeds to spread up to 200 meters from the parent plant, although the final distance varies with wind velocity and local topography (Motti et al., 2021b). Our studies revealed that in the cemetery environment, the highest density of the offspring is at about 5 meters from the female plant (Table 2).

The female individuals, richly fruity, produce a large number of small offspring from seeds (offsprings - seedlings with heights between 5-40 cm). The young offspring (70-100-300 cm in height) may emerge from seeds (older age) or from root sprouts (faster growing). The structural parameters (density - number of individuals, canopy surface, height, trunk diameter at DBH) used to describe the physical characteristics show the diversity of individuals in different life stages.

Ailanthus altissima also reproduces vegetatively through root suckers and stump shoots, allowing rapid regeneration after mechanical damage or pruning. The species lacks a true taproot and instead develops an extensive, asymmetrical root system that adapts to local soil conditions (Soler & Izquierdo, 2024a).

Table 2: The locations of investigated Ailanthus individuals, their life stage, structural parameters, and distance from the mother source

GPS coordinates		Type of life stage	Density	Canopy surface (m^2)	Hight (cm)	Trunk diameter (cm)	Distance from source (m)	Observations
N	E							
44.40356	26.09782	**1 female ♀ (richly fruity)**		**50**	**900**	**60**	**0**	
		male ♂	2	40	800	30	0,1	
		Os-s	7	0.2	30	0.5	1	
		Os-s	10	0.2	10	0.3	1	
		Os-s	4	0.2	30	1.5	3	
		Os-s	7	0.2	10	0.5	3	
		Os-s	1		40		4	
		Os-s	3		30		4	2 deteriorated
		Os-s	4		5-10		4	
		Os-y	1		300		5	
		Os-y	7		70 -100		5	
		Os-s	10		30		5	
		Os-s	15		10-20		5	
		Os-y	1		100		5	
		Os-s	1		60		5	
		Os-s	5		5-20		5	
		Os-s	1		30		6	
		Os-s	1		20		6	
		Os-s	1		20		13	
		male ♂	1		900	30	13	disturbed the wall
		dead	1				15	
		male ♂	1				17	disturbed the wall, lifted the soil
		young	1		500		27	
		Os-cs	2		30 - 50		27	
		Os-cs	2		10		27	
		Os-cs	2		5		27	
		Os-cs	1		5		27	
		Os-cs	3		5-15		27	
		young	1		500	10	27	
		Os-s	1		30		29	
		Os-s	1		5			

GPS coordinates		Type of life stage	Density	Canopy surface (m^2)	Hight (cm)	Trunk diameter (cm)	Distance from source (m)	Observations
N	E							
44.40462	26.09702	**1 female ♀ (richly fruity)**		**25**	**1000**	**70**		
		male ♂	1		1000	50	0.1	
		male ♂	1		1000	60	0.2	20 x 20 m canopy surface together all 3
		male ♂	1		1000	50	0.3	♂
		Os-rs	3		150		1	
		Os-rs	3		200		1	1 x 1 m canopy surface together all 3
		Os-rs	1		250		1	small groups
		Os-rs	2		30		2	1 x 4 m canopy surface together all 2
		Os-rs	2		200		2	small groups
		Os-rs	1		100		2	
		Os-rs	1		70		2	
		Os-s	12		20		2	
		Os-s	1		30		5	
		Os-s	2		5		5	
		Os-s	2		10		5	
		young	1		500	10	5	
		young	2		450	5	5	
		Os-rs	6		300	3	5	
		Os-rs	4		100		5	
		Os-s	4		10		5	
		Os-rs	3		50		5	
		Os-s	3		30		6	
		Os-rs	2		100		7	
		Os-s	2		30		7	
		Os-s	14		5-10		10	
		Os-rs	1		50		10	developed leaves
		Os-rs	6		200-300		10	
		Of-cs	2				10	

Legend: Os-rs = offsprings - possible from root sprouts; Os-s = offsprings - seedlings; Os-cs = offspring - from cut stem; Os-y = offsprings - young

Most roots occur within the top 46 cm of soil, though vegetative sprouts have been recorded as far as 27 meters from the parent tree. When aerial parts of the plant are damaged or die, new shoots frequently emerge from the root network, reinforcing the plant's resilience and persistence. Our site comprises many individuals in different types of the life stages.

Morphologically, *A. altissima* displays a degree of plasticity in leaf development. Leaf forms can vary depending on the origin of the shoot - ranging from unifoliolate to penta-foliolate in root sprouts, and often trifoliolate in seedlings (Soler & Izquierdo, 2024b). This adaptability further enhances its ability to colonize diverse environments and regenerate following disturbance.

Ecologically, *A. altissima* thrives in altered and degraded ecosystems, exhibiting strong associations with anthropogenic habitats such as railway embankments, freeways, urban walkways, and abandoned construction sites (Motti et al., 2021c). Its robust root system not only enables the plant to penetrate compacted substrates but also causes mechanical damage to infrastructure, pavements, and building foundations. In rural landscapes, it commonly invades fencerows, woodland margins, and forest openings, where it outcompetes native vegetation and alters successional trajectories.

The capacity of *A. altissima* to colonize and damage built structures makes it particularly concerning in cultural heritage contexts. In archaeological and historical sites, including cemeteries and monuments, the species contributes to structural degradation through root expansion, fissure enlargement, and substrate disintegration. Its presence in such areas is increasingly reported across southern and eastern Europe, where it threatens the preservation of both natural and cultural heritage assets (Motti et al., 2021a; Soler & Izquierdo, 2024a).

Preliminary observations suggest that the colonization by *Ailanthus altissima*, *Acer negundo,* and several climbing species such as *Parthenocissus quinquefolia* correlates with visible physical damage, including surface disaggregation, mortar loss, and increased moisture retention on marble and limestone structures (Figure 1).

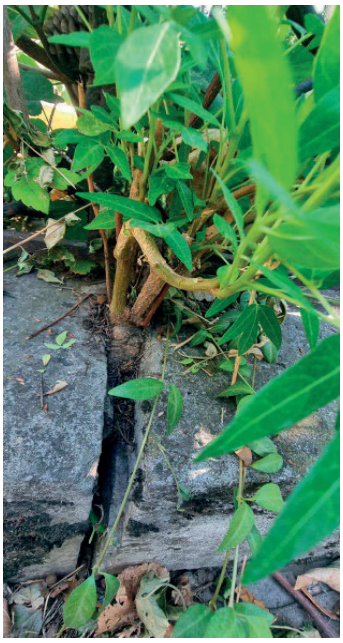

Figure 1. Fissures in the monument through disaggregation

A. altissima has a wide root system, and not all damages are always visible by direct observation. They could be at the foundation or found at a distance of 4 m from the walls, due to the fact that the roots of these trees develop for several meters laterally and vertically.
Ailanthus altissima damages graves and surrounding walls with roots, stems, and fruits (Figure 2).



Figure 2. Stems and roots development pushing and damaging the monument

Among invasive species, *Ailanthus altissima* (tree of heaven) is particularly noteworthy due to its high adaptability to diverse climatic and edaphic conditions and its resistance to eradication efforts. Its rapid growth, efficient vegetative reproduction, allelopathic root activity, and pathogen tolerance explain the ecological success of this aggressive invader (Sladonja et al., 2015). *A. altissima* has been documented on monuments, walls, paved surfaces, and roofs, demonstrating an alarming capacity for propagation.
In the studied fragment of the cemetery, *Parthenocissus quinquefolia exhibits* the same behaviour as *Hedera helix* (common ivy), another species frequently encountered on walls and stone monuments exhibits invasive behaviour as well, although generally to a lesser degree than *A. altissima* (Trotta et al., 2020).
The composition, abundance, and spatial distribution of native and invasive plant species hold considerable bioindicator value for assessing site conditions and guiding conservation management.
The main factors influencing colonization and biodeterioration are: the substrate, site exposure, the surrounding vegetation, and the degree of anthropogenic disturbance.
Taking into account substrate properties, the degree of anthropogenic disturbance, and the surrounding ecological context will be very important for identifying prioritizing maintenance interventions.
The maintenance activity should establish the interaction between invasive plants and substrate type, and thus the vulnerability of the colonized surface in the surrounding environment.
An adaptive management approach will contribute to the conservation of the "Șerban Vodă Cemetery - Bellu" by mitigating biodeterioration more effectively.

CONCLUSIONS

For our studies, Bellu Cemetery - founded in the mid-nineteenth century and now a historical monument of national importance - offers an exemplary context for investigating the impact of invasive plant species on historic monuments. It acts like an open-air laboratory for future more complex and inter-disciplinary studies, an active necropolis and cultural heritage site, exhibiting

a mosaic of ecological niches, ranging from shaded tree canopies to exposed masonry surfaces.

The methods of eradication of woody invasive plant species require a multidisciplinary approach to restoration practices based on strong collaboration between restorers, biologists, agronomists, and masonry experts.

Over the decades, fluctuating management intensity and urban environmental changes have facilitated the establishment of numerous invasive species, making the site a living laboratory for studying their dual impact on biodiversity and built heritage.

The Bellu Cemetery embodies the intersection of urban planning, funerary practice, artistic expression, and national remembrance. It serves as both a functioning necropolis and a cultural patrimony site, illustrating how burial spaces evolve from purely functional grounds to rich symbolic landscapes. Its continued preservation is crucial for understanding Bucharest's historical urban fabric and Romania's collective heritage.

Our studies will grow in space (more sections of the cemetery toward the entire surface) and complexity in the years to come, and the results will contribute to the development of interdisciplinary management strategies that reconcile biodiversity conservation with heritage preservation, ensuring that these cultural landscapes continue to function as both ecological refuges and memorial spaces.

ACKNOWLEDGEMENTS

The research was developed within the framework of projects RO1567-IBB05/2025 and RO1567-IBB01/2025 funded by the Romanian Academy.

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