Biologia Serbica, 2023, 45: 03-09

DOI: 10.5281/zenodo.10402309

Original paper

Bryophyte flora of cemeteries in the City of Novi Sad (Serbia)

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Accepted: 21 July 2023 \ Published online: 10 September 2023

Summary. This study analyzes the bryophyte flora of six old cemeteries in Novi Sad and reports on the findings of the first study on bryophytes in Novi Sad. All investigated cemeteries are more than a hundred years old and are protected by the Institute for Protection of Cultural Monuments of Novi Sad. A total number of 49 bryophyte species was recorded. Although urban habitats are different from native habitats, bryophytes can still survive successfully. The study sheds light on the importance of cemeteries as urban habitats for bryophytes, and highlights the need for further research in this area.

Keywords: graveyard, liverwort, mosses, Novi Sad, urban flora.

INTRODUCTION

Bryophytes are a diverse group of non-vascular plants that are a significant component of urban ecosystems. They are highly adapted to urban environments and can be found growing in a variety of places, from cracks in sidewalks to hanging baskets and even on rooftops. In recent years, there has been a growing interest in urban bryophytes for their potential in providing ecosystem services, such as improving air quality (Anđić et al. 2015), indicating the urban heat island effect (Oishi and Hiura 2017; Oishi 2019b), and increasing biodiversity (Oishi 2019a; Żołnierz et al. 2022).

Cities can contain a large variety of plants and animals (Shwartz et al. 2014). There is much information available about the biodiversity of urban forests and parks (Nielsen et al. 2014), however, cemeteries have been largely neglected. Cemeteries, churchyards, and parks are potential sites for biodiversity conservation in urban areas (Löki et al. 2019). Studies have shown a positive correlation between the number of species, age of monuments, and size of cemeteries (Fudali 2001), making cemeteries a significant factor in conserving biodiversity of plants and some animal taxa (Kowarik et al. 2016). In Serbia alone, there are 831 species of bryophytes (Pantović 2018), making it a bryologically rich country. Despite this, urban areas in Serbia have been relatively underexplored in terms of bryophyte research, with Belgrade (Grdović and Stevanović 2006; Sabovljević and Grdović 2009), and the urban areas of Fruška Gora (Ilić 2019) being some of the few exceptions. Urbanization can create particular microhabitats inhabited solely by bryophytes (Fudali 1994; Sabovljević and Grdović 2009; Skudnik et al. 2013). Cemeteries, with their regular mowing and maintenance, are ideal locations for

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bryophytes to thrive in due to the absence of competitively superior vascular plants (Sabovljević and Grdović 2009). As a result, urban bryophyte vegetation can be particularly interesting in terms of its floristic composition and the presence of rare and significant taxa (Ilić 2019).

The aim of this study was to provide a first comprehensive inventory of bryophyte flora within six old cemeteries in the City of Novi Sad (Serbia).

MATERIAL AND METHODS

Study site

This study was conducted in the City of Novi Sad, located in the southern part of the Pannonian plain (Bačka region) on the left bank of the Danube River, near the Fruška Gora mountain. According to census data from 2022, it has an estimated population of 367000 (Statistical Office of the Republic of Serbia). The altitude of the city is 80 m above sea level, and the lowest measured point is 72 m above sea level. The area of 702.7 km^2 makes Novi Sad the largest town in the Autonomous Province of Vojvodina. The climate is temperate-continental with hot summers and cold winters. During the research period, the average amount of precipitation was 46.18 mm and the average temperature was 13.3 °C (https://www.hidmet.gov.rs/, 2021). The hottest month was July, and the coldest month was January. Phytogeographically, Novi Sad belongs to the Pannonian province, Central European-Balkan-Illyrian sub-region within the Central European phytogeographic region.

The species were collected from six old cemeteries (Fig. 1): the Complex of Catholic cemeteries, Uspensko cemetery, Rusinsko cemetery, Almaško cemetery, Nazarensko cemetery, and Jevrejsko cemetery. The Complex of Catholic cemeteries is the largest cemetery in Novi Sad, covering an area of 7.6 hectares. It was founded in the second half of the 18th century and consists of several smaller cemeteries: Rimokatoličko, Reformatorsko, Evangelističko, Nemačko, and Avijatičarsko. The majority of this area is taken up by monuments, accounting for approximately 80% of the space, while open land covers around 17%, and old trees make up only 3%. The Uspensko cemetery was founded in 1860 and covers an area of 4 hectares. The majority of this area, approximately 75%, is occupied by monuments, while old trees comprise only around 10%. The remaining portion is covered by free soil. The Almaško cemetery was founded in the 18th century and is located on the outskirts of Novi Sad. Its area size is 4.46 hectares. Compared to other cemeteries, the Uspensko cemetery is predominantly characterized by monuments, which occupy approximately 90% of the space. In contrast, free soil accounts for a mere 3% of the area. The Jevrejsko cemetery was founded at the beginning of the 19th

Fig. 1. Cemeteries location and coordinates. **C1**, Jevrejesko cemetery (45.24376°, 19.82872°); **C2**, Complex of Catholic cemetery (45.24777°, 19.82896°); **C3**, Uspensko cemetery (45.25581°, 19.82949°); **C4**, Rusinsko cemetery (45.26005°, 19.82639°); **C5**, Almaško cemetery (45.26812°, 19.82866°); **C6**, Nazerensko cemetery (45.27057°, 19.82682°). (GoogleEarth).

century and covers an area of 1.5 hectares, most of which is occupied by cemetery (~75%) and free soil (~20%). Burials are performed at all the cemeteries mentioned above. Founded in the 19th century, the Nazarensko cemetery is the smallest studied site, with an area size of 0.7 hectares. Despite its historical significance, burials are not carried out at this particular cemetery. Similarly, the Rusinsko cemetery, spanning 0.5 hectares and established in the 19th century, also does not accommodate burials. Taking into account that burials do not take place in the Nazarensko and Rusinsko cemeteries, we observe that the distribution of space differs. In the Nazarensko cemetery, free soil occupies approximately 90% of the area, while monuments make up around 5%. On the other hand, in the Rusinsko cemetery, free soil represents 50% of the space, while monuments account for approximately 45%.

Data collection and analysis

Bryological research was carried out during 2021. The collection of plant material was done during the spring, summer, and autumn in order to obtain specimens from different parts of the life cycle for easier and more accurate identification. Bryological specimens were collected from different types of substrates (concrete, tree bark, stump, marble, brick, stones, soil) and packed in paper bags for later identification. Plant material was deposited in BUNS (Herbarium of the Department of Biology and Ecology, Faculty of Sciences, University of Novi Sad, Serbia). Nomenclature follows Hodgetts et al. (2020), for mosses and Hodgetts and Lockhart (2020) for liverworts.

Taxonomic analysis was performed, as well as floristic similarity analysis between cemeteries according to Sörensen (1948). Furthermore, we analyzed bryophyte preferences to substrate type.

RESULTS

A total number of 49 taxa (1 liverwort and 48 bryophyte species) was recorded (Table 1). Among these, 15 species were pleurocarpous, while the remaining 33 species were acrocarpous mosses. The most common families were Pottiacae, Brachytheciaceae and Bryaceae. Out of the 33 different genera (Fig. 2) belonging to 15 families (Fig. 3), *Tortula* (with 5 species) and *Syntrichia* (with 4 species) had the largest number of species. The highest number of species was found at the Complex of Catholic cemeteries (34 species) and Uspensko cemetery (27), while the lowest number of species was found at the Nazarensko cemetery (9). Jevrejsko, Almaško and Rusinsko cemeteries had 13, 17, and 15 species, respectively. When considering the size of each cemetery and the number of species found within, Rusinsko cemetery had the highest density of 0.003 species/m^2, while Jevrejsko cemetery had the smallest density of 0.00086 species/m^2. *Tortula muralis* and *Grimmia pulvinata* were commonly observed in

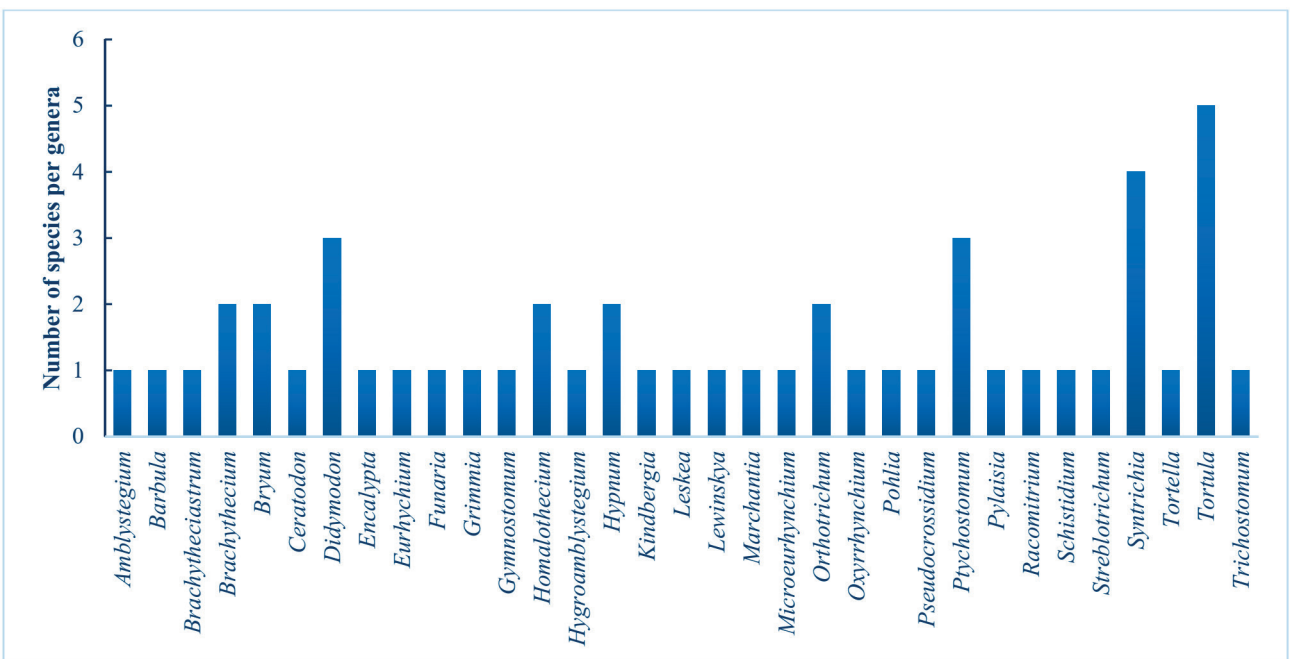

Fig. 2. The taxonomic analysis of bryophyte genera found on investigated cemeteries in Novi Sad City (research period spring, summer, and autumn 2021).

Table 1. Bryophyte species list found at investigated cemeteries in Novi Sad city (research period spring, summer, and autumn 2021).

Species	C1	C2	C3	C4	C5	C6
Amblystegium serpens (Hedw.) Schimp.		+	+		+	
Barbula unguiculata Hedw.		+	+	+	+	
Brachytheciastrum velutinum (Hedw.) Ignatov & Huttunen		+			+	
Brachythecium albicans (Hedw.) Schimp.	+		+			
Brachythecium rutabulum (Hedw.) Schimp.		+				+
Bryum argenteum Hedw.	+	+	+		+	+
Bryum dichotomum Hedw.		+			+	
Ceratodon purpureus (Hedw.) Brid.		+	+		+	
Didymodon fallax (Hedw.) R. H. Zander		+	+	+	+	+
Didymodon insulanus (De Not.) M. O. Hill	+		+			
Didymodon luridus Hornsch.	+	+	+			
Encalypta streptocarpa Hedw.				+		
Eurhynchium striatum (Hedw.) Schimp.		+		+		
Funaria hygrometrica Hedw.		+				
Grimmia pulvinata (Hedw.) Sm.	+	+	+	+	+	+
Gymnostomum aeruginosum Sm.	+					
Homalothecium lutescens (Hedw.) H. Rob.		+	+	+		
Homalothecium sericeum (Hedw.) Schimp.			+			
Hygroamblystegium varium (Hedw.) Mönk.			+			
Hypnum cupressiforme Hedw.		+				
Hypnum jutlandicum Holmen & Warncke	+	+				+
Kindbergia praelonga (Hedw.) Ochyra			+			
Leskea polycarpa Hedw.						+
Lewinskya affinis (Schrad. ex Brid.) F. Lara, Garilleti & Goffinet		+		+		
Microeurhynchium pumilum (Wilson) Ignatov & Vanderp.	+	+	+			
Orthotrichum anomalum Hedw.		+	+	+	+	
Orthotrichum diaphanum Brid.		+	+	+		+
Oxyrrhynchium hians (Hedw.) Loeske		+		+		
Pohlia melanodon (Brid.) A. J. Shaw		+	+			
Pseudocrossidium hornschuchianum (Schultz) R. H. Zander		+	+			
Ptychostomum capillare (Hedw.) Holyoak & N. Pedersen	+	+				
Ptychostomum imbricatulum (Müll. Hal.) Holyoak & N. Pedersen		+				
Ptychostomum moravicum (Podp.) Ros & Mazimpaka	+					
Pylaisia polyantha (Hedw.) Schimp.		+				
Racomitrium affine (F. Weber & D. Mohr) Lindb.		+		+	+	
Schistidium apocarpum (Hedw.) Bruch & Schimp.	+	+	+			
Streblotrichum convolutum (Hedw.) P. Beauv.				+		
Syntrichia montana Nees		+	+		+	
Syntrichia ruraliformis (Besch.) Mans.	+	+	+		+	
Syntrichia ruralis (Hedw.) F. Weber & D. Mohr		+	+		+	+
Syntrichia virescens (De Not.) Ochyra			+		+	
Tortella squarrosa (Brid.) Limpr.			+			
Tortula canescens Mont.		+				
Tortula caucasica Broth.					+	
Tortula lindbergii Broth.		+				
Tortula muralis Hedw.	+	+	+	+	+	+
Tortula truncata (Hedw.) Mitt.		+	+	+	+	
Trichostomum brachydontium Bruch				+		
Marchantia polymorpha L.			+			

Jevrejsko cemetery-C1, Complex of Catholic cemeteries-C2, Uspensko cemetery-C3, Rusinsko cemetery-C4, Almaško cemetery-C5, Nazarensko cemetery-C6

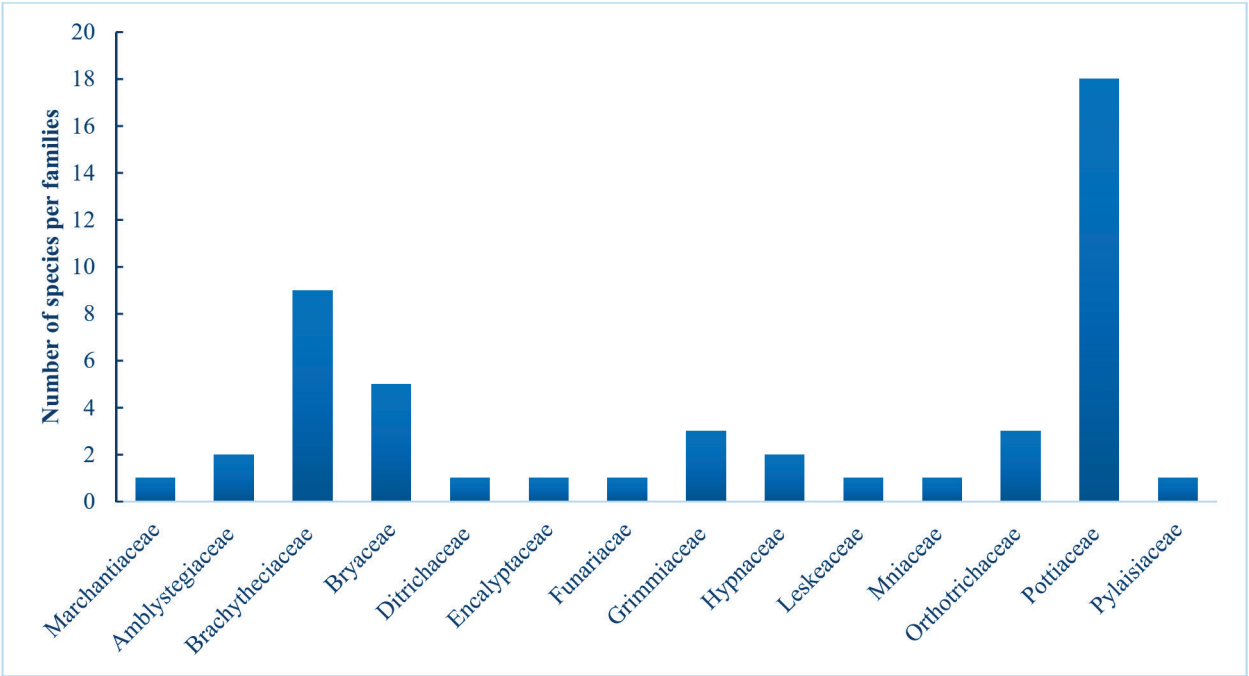

Fig. 3. The taxonomic analysis of bryophytes families found on investigated cemeteries in Novi Sad City (research period spring, summer, and autumn 2021).

all cemeteries on almost all types of substrates, and *Bryum argenteum*, *Brachythecium albicans*, and *B. rutabulum* were also frequently observed.

In relation to the type of substrate, the largest number of species was found on concrete. Precisely, 77% of species were found on concrete, 15% on soil, and the rest on stumps, bricks, tree bark, stone and marble (Fig. 4).

The Index of Similarity showed that the Complex of Catholic cemeteries and Uspensko cemetery had the highest similarity (62.3%), while Jevrejsko cemetery and Rusinsko cemetery had the lowest similarity (Table 2).

DISCUSSION

This type of investigation at cemeteries is becoming more frequent. For instance, Mišiková and Kubinská (2010) listed 67 species of mosses found on old monuments in Slovakia, while Roberts and Ghullam (2015) listed 65 species found in cemeteries in Earlham. Species that appear in cemeteries in many studies (Mišiková et al. 2018; Godovičová et al. 2020), including in Novi Sad, are: *Amblistegium serpens*, *Bryum argenteum*, *Grimmia pulvinata,* and *Tortula muralis*.

The taxonomic analysis of mosses in the researched areas is consistent with the analysis of the moss flora of Serbia (Pantović 2018) because the families Pottiaceae, Brachytheciaceae, Grimmiaceae, and Bryaceae appear among the most species-rich families in the bryoflora of Serbia.

The ability to tolerate desiccation is a survival strategy observed in many bryophytes, including representatives of the Pottiaceae family (Oliver et al. 2005) such as the dominant genera *Tortula* and *Syntrichia*. The genus *Syntrichia* is commonly found growing on stones, walls, concrete paths, and sunny calcareous areas (Atherton et al. 2010), which are typical substrates in cemeteries. The genus *Tortula*, on the other hand, is often found in urban environments and can grow on various habitat rocks, calcareous soil, damp tarmac, brick, and both sunny and shaded locations (Atherton et al. 2010).

Within the Brachytheciaceae family, three species were discovered: *Brachythecium albicans*, *B. rutabulum*, and *B. velutinum*. These species are capable of growing on acidic soil, rocks, living trees, and dead wood. They are typically found in open habitats and rarely occur in shaded areas (Atherton et al. 2010). In the City of Novi Sad, *B. albicans* was observed on concrete, while the other two species were found on soil.

Considering the presence of old trees in all of the cemeteries, the expected occurrence of the Orthotrichaceae family is confirmed. A total of three species from this family were identified. The closest area that has been studied for bryophytes is the Fruška Gora Mountain (Ilić 2019), where 220 species of bryophytes were found. Notably, Ilić (2019) discovered 90 species specifically within urban habitats on the Fruška Gora Mountain. When considering the size of the

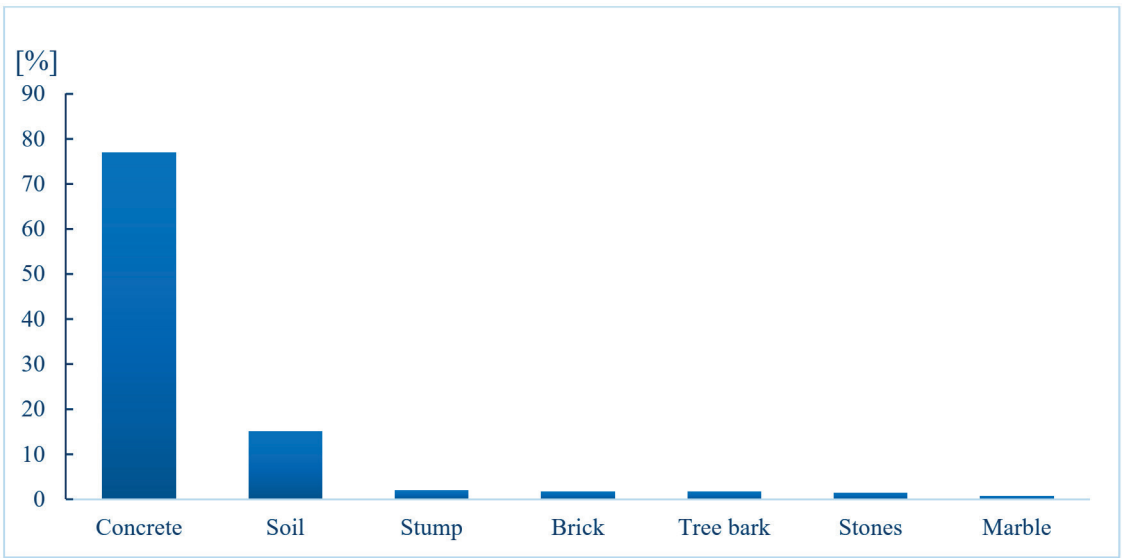

Fig. 4. Substrate preferences of species found on investigated cemeteries in Novi Sad City (research period spring, summer, and autumn 2021).

cemeteries in comparison to Fruška Gora, it can be inferred that cemeteries act as genuine oases for bryophytes within urban environments. Despite the high degree of urbanization, we conclude numerous bryophyte species thrive within these cemetery settings.

Average similarity between all of cemeteries is 39,35%. This average is considered high, which is expected given that they are all in similar environmental conditions.

The comparable distribution of habitat types, namely monuments, old trees, and free soil, between the Complex of Catholic cemeteries and Uspensko cemetery results in a greater similarity of taxa. Among a total of 49 moss species, the Complex of Catholic cemeteries exhibits the highest species count, with 34 species recorded. This can be attributed to the larger size of the cemetery, which provides a more extensive range of habitats. Additionally, since the majority of this cemetery is occupied by monuments, it is expected that the highest number of species would be found in this particular habitat, representing approximately 80% of the species diversity.

The Uspensko cemetery, despite being smaller than the Complex of Catholic cemeteries, still showcases a similar representation of monuments, free soil, and old trees. The relatively high number of species observed in this cemetery can be associated with reduced traffic or less human activity surrounding the area, allowing for a more favorable environment for bryophytes.

Upon examining the ecological aspects of the habitat, it becomes apparent that the highest number of species is found on monuments, specifically on concrete surfaces. There is a comparatively smaller representation of terricolous species in this habitat, while epiphytes are the least represented. Considering the area that was investigated, this relationship of habitat preferences is expected.

This study provides the first insight into urban bryophyte flora of Novi Sad, and is also an addition to the bryoflora of Serbia. A total of 49 species were recorded, all of which are on Serbia's bryophyte list. Based on these findings,

Table 2. Sörensen similarity index of bryoflora between investigated cemeteries (research period spring, summer, and autumn 2021).

	Almaško cemetery	Jevrejsko cemetery	Nazarensko cemetery	Complex of Catholic cemeteries	Rusinsko cemetery	Uspensko cemetery
Almaško cemetery		26.66	30.76	54.9	43.75	59.09
Jevrejsko cemetery			27.27	29.78	14.28	45
Nazarensko cemetery				37.20	33.33	38.88
Complex of Catholic cemetery					48.97	62.29
Rusinsko cemetery						38.09

All obtained values are expressed in %.

we can conclude that the cemeteries of Novi Sad are rich in bryophytes. Further research of urban habitats is necessary in Novi Sad and throughout Serbia to study the ecology, biology, and conservation possibilities of urban bryophytes.

ACKNOWLEDGMENTS

This research is funded by Ministry of Science, Technological Development and Innovations of the Republic of Serbia, Grant No. 451-03-47/2023-01/200125.

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