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DIVERSITY OF WOODY PLANTS IN URBAN PARKS OF SKOPJE, NORTH MACEDONIA

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SUMMARY

Urban parks are crucial components of a city's green infrastructure, offering significant benefits from both social and environmental perspectives. They provide many ecosystem services and play a key role in maintaining, preserving, and enhancing urban biodiversity. This paper analyses the woody plant diversity in three urban parks in Skopje, North Macedonia. The research identified 90 different woody plant taxa in the analyzed parks, belonging to 42 genera and 23 families. The parks have a significantly higher number of non-native taxa compared to the native ones, as well as a significantly higher number of deciduous taxa compared to evergreen taxa. Although non-native species dominate to a great extent over the native ones, there is no threat from invasive plant species in the researched parks. Furthermore, the analyses included the calculation of biodiversity indices (alpha indices: Shannon, Simpson, and Berger-Parker, and also Sørensen beta index). The results showed that none of the parks are highly significant from a biodiversity perspective. The alpha indices indicate a low to moderate biodiversity in the studied North Macedonian urban parks. On the other hand, the Sørensen beta index indicated a more positive view, emphasizing the lack of significant similarity among the studied urban parks. Nevertheless, there is a clear need to enhance the biodiversity of woody plants in urban parks in Skopje. Integrating biodiversity considerations into the process of planning, landscape design of urban parks, and their maintenance is crucial. Establishing biodiversity monitoring as a standard practice will be essential for understanding the real situation in urban parks and enabling timely interventions.

KEY WORDS: woody plants, dendroflora, trees and shrubs, diversity, biodiversity indices, horticulture, urban parks

INTRODUCTION

Urban parks are essential components of urban green infrastructure (Breuste et al. 2015). They provide numerous ecosystem services, with biodiversity being one of the most important (Lakičević et al. 2022). These parks serve as specific urban green places, acting as habitats for various flora and fauna, thereby representing significant biodiversity hotspots within cities (Nielsen et al. 2014, Vidaković et al. 2020). As urbanization continues to rise, the fundamental importance of conserving urban biodiversity remains a subject of ongoing debate (Nilon 2011), with growing interest in this area (Cornelis and Hermy 2004, Dearborn and Kark 2010). One of the key methods for preserving biodiversity within urban habitats is monitoring changes in biodiversity over time (Volis 2018, Shilling et al. 2020, Lakičević et al. 2022). This procedure is useful for determining the presence of species, their persistence, or their potential loss from the area.

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The variety of organisms and the measurement of their diversity have long been of interest to ecologists, particularly in natural habitats (Sohrabi and Habashi 2011). Nowadays, the diversity of tree species has also become a popular and interesting research topic for urban foresters and landscape designers (Hilbert et al. 2023). Greater diversity increases the functionality of trees, making their roles in urban environments more significant (Zare et al. 2009). An increase in plant species within man-made urban ecosystems can enhance environmental sustainability (Fard et al. 2015). This understanding of biodiversity allows for timely interventions during the urban planning process. Moreover, trees as dominant landscape elements in many urban areas and parks also influence other aspects of biodiversity. This makes them an important consideration in urban management decisions (Nowak 2010), further highlighting their crucial role in enhancing urban biodiversity (Vidaković et al. 2020).

In the past, analyses showed that biodiversity played a limited role in urban planning, often overshadowed by other priorities (Miller et al. 2009). However, recommendations to focus on challenging and relevant hypotheses, evaluate outcomes, and make knowledge actionable to provide specific guidance, tools, and workflows to increase biodiversity's influence in urban planning (Norton et al. 2016) are becoming more relevant today. Certain studies have found a positive correlation between biodiversity in urban parks and well-being, suggesting that urban planners should prioritize enhancing diversity in urban green spaces (Brown and Grant 2005, Wood et al. 2018). Taylor and Hochuli (2015), in their study on creating better cities, emphasize the importance of considering biodiversity during the design process. They argue that urban designers should recognize the potential of their work to enhance human well-being by integrating biodiversity into their design and research.

In recent years, the diversity of woody plants in urban parks has become an increasingly researched topic (Bo and Zhi-Yi 2003; Cornelis and Hermy 2004; Poljak et al. 2011; Tafra et al. 2012, 2013; Nielsen et al. 2014; Zebec et al. 2014; Sahani and Raghavaswamy 2018; Savosko et al. 2020; Vidaković et al. 2020; Çoban et al. 2021; Öğçe et al. 2022; Zibtseva 2022; Lakičević et al. 2022; Ma et al. 2023). These studies typically analyze various aspects such as the number of species and varieties, the presence of deciduous and evergreen taxa, as well as the presence of woody plants by life form, and the number of native and non-native species. Beyond these common methods of studying and analyzing diversity, biodiversity in an area can also be measured in two distinct ways that include alpha and beta diversity indices (Heip et al. 1998, Gotelli and Colwell 2001, Stirling and Wilsey 2001). The most commonly used indices for determining biological diversity are alpha indices, such as the Shannon index (Shannon 1948), which measures both richness and evenness, and the Simpson index (Simpson 1949), which focuses on evenness. These indices are determined by the number of different taxa and their presence in a given area. Another alpha index that measures evenness is the Berger-Parker index (Berger and Parker 1970), which, in addition to considering the number of different taxa and their distribution, also takes into account the dominance of particular taxa. This makes it quite significant from the perspective of urban planning and landscape design, as dominant taxa influence the design and style of the park (Kümmerling and Müller 2012). Unlike alpha indices, which measure diversity within a single area, beta diversity indices are used to compare biodiversity between different areas or, less frequently, within the same area over different time periods (Legendre 2019, Lakičević et al. 2022). Understanding beta-diversity indices is essential for protecting regional diversity (Socolar et al. 2016) and can directly assist urban planning. This comprehensive approach to studying the diversity of woody plants in urban parks not only provides valuable ecological insights but also supports effective urban planning and landscape design.

Urban parks and urban dendroflora in North Macedonia (Shotaroska et al. 2019, Stipanović et al. 2022, Dimitrova et al. 2023, Stipanović and Andonovski 2024) have rarely been mentioned in research, presenting a significant opportunity for investigation. This study aimed to assess the current state of urban woody plant diversity in three North Macedonian parks and identify potential actions to enhance it. The focus was on preserving and improving biodiversity and enhancing the overall quality of life for urban residents. The specific objectives of this research were: (1) to determine and examine the abundance of woody plant taxa, their family affiliation, and the number of native, non-native, and invasive taxa; and (2) to analyze the diversity of woody plants in the studied parks using various biodiversity indices, including the alpha indices (Shannon, Simpson and Berger-Parker) and the Sørensen beta index.

MATERIALS AND METHODS

Study area

The research was conducted in three urban parks in Skopje, North Macedonia: Macedonia 1 Park, Airplane Park, and Woman-Warrior Park. These parks are all located in the central city area of Skopje, each within a different municipality (Figure 1).

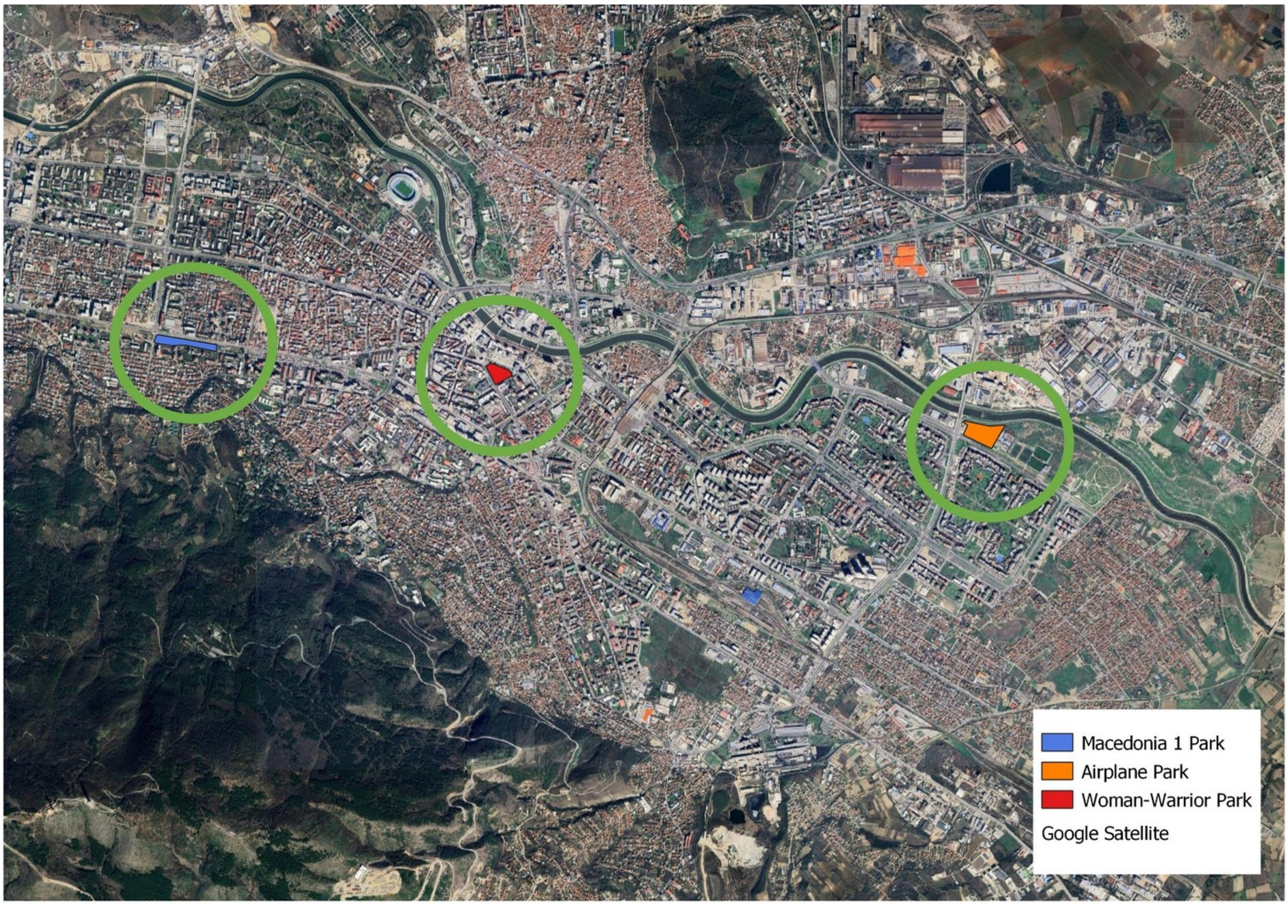

Figure 1 Locations of the analyzed parks in Skopje (North Macedonia).

Macedonia 1 Park is situated in the municipality of Karposh, in the settlement of Kapishtec. It is a linear park, bordered to the north by Metropolit Teodosij Golaganov Boulevard and to the south by Jurij Gagarin Street. Established in 2012, the park has been progressively enhanced over the years with a variety of plantings. This park is multifunctional, comprising various elements or sections, including a recreational area with an outdoor gym and white gravel trim trail, children's play area and a playground, a cycling track for children, space for quiet relaxation, and a dog park. Each section offers a range of activities. Due to its diverse offerings and the densely developed nature of the Kapishtec settlement, along with the scarcity of large parks in the area, Macedonia 1 Park plays a crucial role for the local community.

Airplane Park is located in the municipality of Aerodrom, within the settlement of Novo Lisiche. On one side, it borders the Vardar River, while on the other, it is bordered by ASNOM Boulevard. This park is frequently visited by local residents, primarily due to its location next to the Vardar River quay and the opportunity to enjoy the cherry blossoms during a certain period of the year. Additionally, it offers a variety of recreational options, including a cafeteria, a restaurant, various children's play equipment, and a basketball court.

Woman-Warrior Park is in the municipality of Centar, right in the city center, next to the city's oldest shopping center. Due to its location and, primarily, the shade from the old trees and resting areas, the park is always filled with passers-by who stop to rest.

All selected parks are classified as urban parks. Macedonia 1 Park and Airplane Park are relatively new, created in the previous decade, while Woman-Warrior Park is the oldest, established in the early 1970s (Table 1).

Although the three parks vary in size, they have some similarities in vegetation. Both Macedonia 1 Park and Woman-Warrior Park feature a diverse array of vegetation, including trees, shrubs, linear groups of shrubs, and

Table 1 Basic characteristics of the studied parks in Skopje (North Macedonia).

Park	Area	Period of construction
Macedonia 1 Park	2.33 ha	2012-2016
Airplane Park	3.41 ha	2012
Woman-Warrior Park	1.62 ha	1970-1973

floral compositions. In contrast, Airplane Park is characterized solely by the presence of trees. All three parks are designed with a combination of informal and formal styles, with the informal style predominating. However, formal elements are also present, not only in the inanimate features such as paths and monuments but also in the plant compositions, particularly through the use of formal hedges created from shrubs. The presence of these formal elements is significant as they greatly impact the assessment of biodiversity values within the parks.

Field data collection

The data for this study were collected from the beginning of March 2023 to the end of July 2024. All woody plants (trees and shrubs) were marked using a GARMIN GPS MAP 66sr and processed with QGIS (Quantum Geographic Information System) software. Plant determination was conducted using literature on dendrology, including books by Džekov (1988), Šilić (1990), Idžojtić (2009), and databases from World Flora Online (WFO 2024), Royal Botanic Gardens, Kew (Kew 2024), and The Royal Horticulture Society (RHS 2024). Scientific names of taxa are listed according to the International Plant Names Index (IPNI 2025) and World Flora Online (WFO 2024). The authorities for scientific names are standardized according to Brummitt and Powell (1992). Cultivar names are provided according to Hoffman (2021), in accordance with the new guidelines in the "International Code of Nomenclature for Cultivated Plants" (ICNCP), which appeared in 2016 (Brickell et al. 2016). Family affiliations are listed according to Cronquist (1981), Dahlgren et al. (1985), Kramer and Green (1990), and Farjon (2010). Additionally, literature by Vidaković et al. (2020) and Idžojtić et al. (2019) was consulted. Finally, a list of all woody plants and the number of individuals belonging to each taxon for each park was compiled and used to analyze biodiversity.

Woody plant diversity analyses

Based on the collected data, a dendrological analysis of woody plants in the parks of Skopje was conducted. The analysis included the following data: the abundance of individual taxa (species, varieties, forms, hybrids, and cultivars), family affiliation, the number of woody plant taxa and plants by leaf habit, life form, and the number of native, non-native, and invasive taxa. Invasive taxa were identified according to the Global Register of Introduced and Invasive Species for North Macedonia by Trajanovski et al. (2020). Additionally, the diversity of woody plants in the studied parks was calculated using the following indices: Shannon, Simpson, Berger-Parker and Sørensen. All taxa, including hybrids and cultivars, were included in the analyses, with hybrids and cultivars of native species being classified as native, and those of non-native species classified as non-native.

The Shannon index (H') (Shannon 1948) describes both richness and evenness and is obtained based on the formula:

$$H' = -\sum_{i=1}^{s} p_i \ln (p_i)$$

where:

p_i represents the proportion of the number of taxa,

i is the total number of plants present in a given area, and

s is the total number of registered plant taxa.

The Shannon index does not have a fixed range of values but usually takes values between 1.5 and 3.5 (Magurran 2003). If the value is equal or higher than 4, the area is considered extraordinary from a biodiversity perspective.

The Simpson index (D) (Simpson 1949) is a measure for evenness. The values of this index range from 0 to 1, with higher values indicating greater uniformity within the taxa of the analyzed area. The formula used to calculate the Simpson index is as follows:

$$D = 1 - \sum_{i=1}^{s} p_i^2$$

where:

p_i represents the proportion of the number of plants of the taxa,

i is the total number of plants that are present in a given area, and

s represents the total number of plants present in a given area.

The Berger-Parker index (d) (Berger and Parker 1970) quantifies the relative abundance of the most dominant taxa. The index values range from 0 to 1, where values closer to 0 indicate higher diversity, and a value of 1 signifies a monoculture. This index is calculated using the formula:

$$d = \frac{N_{max}}{N}$$

where:

N represents the total number of plants, and

N_{max} represents the number of plants of the most abundant taxa.

The Sørensen index (Sørensen 1948) is a beta index that measures the similarity in plant composition between urban parks. The index values range from 0 to 1, with higher values, closer to 1, indicating greater similarity in the composition of plant taxa. The index is calculated using the formula:

$$SI = (2 * EC)/(E1 + E2)$$

where:

EC is the total number of plants in common between two areas,

E1 is the number of plants in Area 1 (Park 1), and

E2 is the number of plants in Area 2 (Park 2).

RESULTS

The woody plant diversity in the selected parks included 90 different taxa (60 tree taxa and 30 shrub taxa), belonging to 23 different families (Table 2). The Cupressaceae family was characterized with the highest number of taxa, with 19, while the Rosaceae family was characterized with the highest number of woody plants,

Table 2 List of woody taxa in the studied parks of Skopje (North Macedonia). Native woody plant taxa are given in green, invasive woody plant taxa are given in red.

	Taxon	Family	Macedonia 1 Park	Airplane Park	Women-Warrior Park	Total
1	*Abies concolor* (Gordon) Lindl. ex Hildebr.	Pinaceae	/	/	2	2
2	*Acer saccharinum* L.	Sapindaceae	/	/	4	4
3	*Acer negundo* L.	Sapindaceae	/	/	5	5
4	*Acer palmatum* 'Elegans'	Sapindaceae	/	/	9	9
5	*Acer platanoides* L.	Sapindaceae	/	/	2	2
6	*Acer platanoides* 'Globosum'	Sapindaceae	/	/	3	3
7	*Acer pseudoplatanus* L.	Sapindaceae	/	/	4	4
8	*Aesculus hippocastanum* L.	Sapindaceae	/	/	1	1
9	*Albizia julibrissin* Durazz.	Fabaceae	8	1	/	9
10	*Berberis thunbergii* DC.	Berberidaceae	/	/	5	5
11	*Betula pendula* Roth	Betulaceae	7	/	8	15
12	*Betula pendula* 'Youngii'	Betulaceae	12	/	/	12
13	*Buxus microphylla* Siebold et Zucc.	Buxaceae	29	/	/	29
14	*Buxus sempervirens* L.	Buxaceae	167	/	/	167
15	*Catalpa bignonioides* 'Nana'	Bignoniaceae	/	2	/	2
16	*Catalpa bignonioides* Walter	Bignoniaceae	11	/	/	11
17	*Cedrus atlantica* (Endl.) Manetti ex Carrière	Pinaceae	/	/	1	1
18	*Cedrus deodara* (Roxb. ex D.Don) G.Don	Pinaceae	/	/	16	16
19	*Chaenomeles speciosa* (Sweet) Nakai	Rosaceae	/	/	1	1
20	*Chamaecyparis lawsoniana* 'Alumii'	Cupressaceae	3	/	/	3
21	*Chamaecyparis pisifera* 'Boulevard'	Cupressaceae	5	/	/	5
22	*Cotoneaster horizontalis* Decne.	Rosaceae	5	/	/	5
23	*Cupressus sempervirens* L.	Cupressaceae	/	/	3	3
24	*Elaeagnus angustifolia* L.	Elaeagnaceae	2	/	/	2
25	*Euonymus fortunei* 'Emerald 'n' Gold'	Celastraceae	1	/	/	1
26	*Fraxinus americana* L.	Oleaceae	9	1	/	10
27	*Fraxinus angustifolia* Vahl	Oleaceae	/	/	2	2
28	*Fraxinus excelsior* L.	Oleaceae	8	9	/	17
29	*Fraxinus excelsior* 'Jaspidea'	Oleaceae	4	/	/	4
30	*Fraxinus excelsior* 'Nana'	Oleaceae	91	/	3	94
31	*Fraxinus excelsior* 'Pendula'	Oleaceae	5	/	/	5
32	*Ginkgo biloba* L.	Ginkgoaceae	18	/	/	18
33	*Ginkgo biloba* 'Mariken'	Ginkgoaceae	5	/	/	5
34	*Hedera helix* L.	Araliaceae	1	/	/	1
35	*Jasminum nudiflorum* Lindl.	Oleaceae	3	/	/	3
36	*Juniperus chinensis* 'Stricta'	Cupressaceae	3	/	/	3
37	*Juniperus communis* 'Hibernica'	Cupressaceae	5	/	/	5
38	*Juniperus horizontalis* Moench	Cupressaceae	1	/	2	3
39	*Juniperus scopulorum* 'Blue Arrow'	Cupressaceae	10	/	/	10
40	*Juniperus scopulorum* 'Skyrocket'	Cupressaceae	21	/	2	23
41	*Juniperus virginiana* L.	Cupressaceae	/	/	2	2
42	*Liriodendron tulipifera* L.	Magnoliaceae	39	9	3	51

	Taxon	Family	Macedonia 1 Park	Airplane Park	Women-Warrior Park	Total
43	*Lonicera ligustrina* var. *yunnanensis* Franch.	Caprifoliaceae	2	/	7	9
44	*Magnolia grandiflora* L.	Magnoliaceae	/	/	1	1
45	*Magnolia kobus* DC.	Magnoliaceae	/	/	1	1
46	*Magnolia* × *loebneri* Loebner	Magnoliaceae	44	/	/	44
47	*Magnolia liliiflora* Desr.	Magnoliaceae	/	/	6	6
48	*Magnolia* × *soulangeana* Soul.-Bod.	Magnoliaceae	1	/	/	1
49	*Metasequoia glyptostroboides* Hu et W.C.Cheng	Cupressaceae	3	/	/	3
50	*Parthenocissus quinquefolia* (L.) Planch.	Vitaceae	18	/	/	18
51	*Picea abies* (L.) H.Karst.	Pinaceae	/	/	13	13
52	*Picea glauca* 'Conica'	Pinaceae	2	/	/	2
53	*Picea pungens* f. *glauca* (Regel) Beissn.	Pinaceae	/	/	14	14
54	*Pinus mugo* Turra	Pinaceae	2	/	/	2
55	*Pinus nigra* J.F.Arnold	Pinaceae	1	/	95	96
56	*Pinus sylvestris* L.	Pinaceae	/	/	5	5
57	*Platanus occidentalis* L.	Platanaceae	/	/	5	5
58	*Platanus orientalis* L.	Platanaceae	/	107	13	120
59	*Platanus* × *hispanica* Mill. ex Münchh.	Platanaceae	56	32	/	88
60	*Platycladus orientalis* 'Aurea Nana'	Cupressaceae	5	/	/	5
61	*Prunus avium* (L.) L.	Rosaceae	/	3	/	3
62	*Prunus cerasifera* 'Nigra'	Rosaceae	31	/	/	31
63	*Prunus serrulata* 'Kanzan'	Rosaceae	/	131	/	131
64	*Prunus laurocerasus* 'Rotundifolia'	Rosaceae	/	/	33	33
65	*Pseudotsuga menziesii* (Mirb.) Franco	Pinaceae	/	/	1	1
66	*Pyracantha coccinea* M.Roem.	Rosaceae	/	/	4	4
67	*Quercus robur* (Fastigiata Group) 'Koster'	Fagaceae	3	/	/	3
68	*Quercus robur* L.	Fagaceae	/	/	2	2
69	*Quercus rubra* L.	Fagaceae	1	/	1	2
70	*Rosa helenae* Rehder et E.H.Wilson	Rosaceae	/	/	53	53
71	*Rosa* Floribunda Group	Rosaceae	225	/	/	225
72	*Salix* × *sepulcralis* 'Chrysocoma'	Salicaceae	6	/	/	6
73	*Salix babylonica* 'Tortuosa'	Salicaceae	/	/	1	1
74	*Scandosorbus intermedia* (Ehrh.) Sennikov	Rosaceae	6	/	2	8
75	*Spiraea japonica* 'Little Princess'	Rosaceae	32	/	/	32
76	*Taxus baccata* L.	Taxaceae	/	/	3	3
77	*Taxus baccata* 'Fastigiata'	Taxaceae	7	/	/	7
78	*Thuja occidentalis* 'Brabant'	Cupressaceae	1	/	/	1
79	*Thuja occidentalis* 'Columna'	Cupressaceae	/	/	3	3
80	*Thuja occidentalis* 'Europa Gold'	Cupressaceae	/	/	1	1
81	*Thuja occidentalis* 'Globosa'	Cupressaceae	254	/	42	296
82	*Thuja occidentalis* 'Rheingold'	Cupressaceae	1	/	/	1
83	*Thuja occidentalis* 'Smaragd'	Cupressaceae	4	/	/	4
84	*Thuja occidentalis* 'Woodwardii'	Cupressaceae	/	/	27	27
85	*Thuja plicata* Donn ex. D.Don	Cupressaceae	/	/	2	2
86	*Tilia cordata* Mill.	Malvaceae	3	/	/	3
87	*Tilia tomentosa* Moench	Malvaceae	3	/	6	9
88	*Ulmus glabra* 'Exoniensis'	Ulmaceae	4	/	/	4
89	*Ulmus glabra* 'Pendula'	Ulmaceae	6	/	/	6
90	*Wisteria sinensis* (Sims) DC.	Fabaceae	26	/	/	26

Table 3 The number of woody plant taxa and plants by leaf habit, life form, and origin in researched parks of Skopje (North Macedonia).

Category	Number of taxa				Number of plants			
	Macedonia 1 Park	Airplane Park	Woman Warrior Park	Total	Macedonia 1 Park	Airplane Park	Woman Warrior Park	Total
Evergreen/deciduous	20/33	0/9	21/24	37/53	523/697	0/295	269/150	792/1142
Evergreen/deciduous trees	3/26	0/9	16/20	17/43	32/386	0/295	161/84	193/765
Evergreen/deciduous shrubs	17/7	0/0	5/4	20/10	491/311	0/0	108/66	599/377
Conifers/broadleaves	17/36	0/9	18/27	31/59	328/892	0/295	232/187	560/1374
Conifer/broadleaves trees	4/25	0/9	15/21	17/43	35/383	0/295	161/84	196/762
Conifer/broadleaves shrubs	13/11	0/0	3/6	14/16	293/509	0/0	71/103	364/612
Trees	29	9	36	60	418	295	245	958
Shrubs	24	0	9	30	802	0	174	976
Native taxa	9	3	11	18	194	119	141	454
Non-native taxa	44	6	34	72	1026	176	278	1480
Invasive taxa	0	0	1	1	0	0	5	5
Total	53	9	45	90	1220	295	419	1934

totaling 526, which included 11 different taxa found in the researched parks. There were 42 different genera, and 21 of them have representatives of only one taxon, with five of them represented only by a single woody plant (*Aesculus* L., *Chaenomeles* Lindl., *Euonymus* L., *Hedera* L. and *Pseudotsuga* Carrière). The *Thuja* L. genus had the highest number of taxa, with eight taxa, and it also had the largest number of woody plants, totaling 335. Other genera with a higher number of taxa included *Acer* L., *Fraxinus* Tourn. ex L. and *Juniperus* L., each represented by six taxa, and *Magnolia* Plum. ex L., which was represented by five taxa. Of the total 90 different taxa, 33 were cultivars, four were hybrids, one was a variety, one was a form, and one was a cultivar of a hybrid. The remaining 51 taxa were species.

The number of woody plant taxa and plants by leaf habit, life form, and origin in researched parks of Skopje (North Macedonia) is presented in Table 3. Of the total number of woody plant taxa in all three parks, the ratio of evergreen to deciduous taxa was 41:59% (28:72% for trees and 67:33% for shrubs), and the ratio of conifers to broadleaves was 34:66% (28:72% for trees and 47:53% for shrubs) (Table 3). The ratio of evergreen to deciduous woody plants was 41:59% (20:80% for trees and 61:39% for shrubs), and the ratio of conifers to broadleaves was 29:71% (20:80% for trees and 37:63% for shrubs).

All native taxa in the studied parks are marked in green in Table 2. Only 18 of the 90 different taxa (15 tree taxa and three shrub taxa) were categorized as native (Table 3). This indicates that non-native taxa were predominantly present in the researched parks. The ratio between native and non-native woody taxa was 20:80%. In Macedonia 1 Park, there were only nine native plant taxa (17%) out of a total of 53, including six native tree taxa (21%) out of 29, and three native shrub taxa (12.5%) out of 24. Airplane Park had only three native taxa out of a total of nine (all native trees), and Woman-Warrior Park had 11 native taxa (24%) out of 45, all of which were native trees (Table 3). The largest number of native woody plants was in Macedonia 1 Park, with 194 or 16% of all native woody plants (1220) (Table 3). However, considering that all native shrubs were in this park (170 shrubs or 21% of all shrubs in the park), Macedonia 1 Park had the smallest number of native trees (only 24 trees or 6% of all 418 trees in the park) compared to other researched parks (Airplane Park with 119 plants or 40% of a total 295, and Woman-Warrior Park with 141 individuals or 37% native individuals of a total of 419) (Table 3).

Of the 72 non-native woody plant taxa present in the researched parks, only one, *Acer negundo* L., was invasive. This species was found only in one of the researched parks (Woman-Warrior Park), with just five trees (Table 2, Table 3).

Table 4 The Shannon, Simpson, and Berger-Parker indices of woody plant diversity in the studied parks.

Park	Shannon index	Simpson index	Berger-Parker index
Macedonia 1 Park	2.66	0.89	0.53
Airplane Park	1.30	0.66	0.92
Woman-Warrior Park	2.76	0.89	0.53

Table 5 Sørensen index of woody species biodiversity between the studied parks.

Sørensen index	Macedonia 1 Park	Airplane Park	Woman-Warrior Park
Macedonia 1 Park	1		
Airplane Park	0.23	1	
Woman-Warrior Park	0.36	0.12	1

The values of the alpha biodiversity indices in the studied parks are shown in Table 4. The Shannon index had the highest value of 2.76 in Woman-Warrior Park, slightly lower in Macedonia 1 Park at 2.66, and significantly lower in Airplane Park at 1.30. The Simpson index had especially high values in two of the parks, Macedonia 1 Park and Woman-Warrior Park, both with a value of 0.89, indicating a quite highly homogeneous distribution of plant taxa in these parks. In Airplane Park, the value was slightly lower, at 0.66. Furthermore, the Berger-Parker index was the highest in Airplane Park (0.92), indicating very low diversity. The values of the Berger-Parker index in the other two parks were lower, 0.53 for both Macedonia 1 Park and Woman-Warrior Park, but they still represent a quite high abundance of the most dominant taxa.

Using the Sørensen beta index, the similarity between the researched parks was determined. The values of the Sørensen index of woody species biodiversity between the selected parks are presented in Table 5. In accordance with this research, the greatest similarity, with a Sørensen index value of 0.36, was observed between Macedonia 1 Park and Woman-Warrior Park. However, this value still indicates very small similarity. The remaining Sørensen index values were notably low: 0.12 between Airplane Park and Woman-Warrior Park, and 0.23 between Macedonia 1 Park and Airplane Park, indicating significant differences in their plant compositions.

DISCUSSION

The presence of deciduous broadleaved taxa dominates the entire researched area, as well as each of the individual parks. From the analysis of trees, it is evident that deciduous broadleaved tree taxa are dominant. Moreover, in one of the parks (Airplane Park), the absence of evergreen plants is noticeable, with all woody plants being deciduous broadleaved. Although the shade provided by deciduous trees is considered the optimal shading solution and effectively meets the demands for thermally comfortable spaces (Xu et al. 2019), this choice of vegetation creates empty landscapes in late autumn and winter, negatively impacting biodiversity and the maintenance of ecosystem services (Nagendra and Gopal 2011). In addition, the analysis of shrubs shows that evergreen and broadleaved shrubs are dominant in the studied parks.

The presence of native woody taxa and the abundance of native plants across all the surveyed parks in Skopje are notably low. According to some authors (Lanta et al. 2013, Lakičević et al. 2022, Öğçe et al. 2022), urban spaces should prioritize the selection of native species over non-native ones. In general, native species are better adapted to local climate conditions and can significantly improve the quality of urban ecosystems. In addition, these species are crucial for maintaining local biodiversity, supporting wildlife, and providing ecosystem services. Besides being better adapted to the local environment and climatic conditions, they require less maintenance and, in terms of decorativeness, they are not inferior to non-native species (Tafra et al. 2012). Nevertheless, non-native species are often chosen over native ones for urban landscaping due to their aesthetic appeal, fast growth, beautiful flowers, interesting foliage, and exotic appearance (Idžojtić et al. 2010, 2011, 2013; Poljak et al. 2011; Špaková and Šerá 2018). People often enjoy introducing exotic plants to create visually appealing and diverse landscapes (Zebec et al. 2014). However, the replacement of native species with non-native ones can undermine essential ecological functions provided by vegetation, and some of these functions may be completely lost (Talal and Santelmann 2019). Ultimately, this can negatively affect biodiversity in the urban environment. Although a significant number of studies have found that in urban parks, non-native taxa are more prevalent than native ones (Rauš 1969; Karavla 1997; Godefroid 2001; Wania et al. 2006; Shochat et al. 2010; Poljak et al. 2011; Tafra et al. 2012, 2013; Zebec et al. 2014; Gaertner et al. 2017; Pušić et al. 2023), there are also examples where native species have increased and non-native taxa have decreased in certain parks. For example, in King Petar Krešimir IV Park in Zagreb, Croatia, this shift occurred between 1995 and 2020 as a result of efforts focused on preserving biodiversity (Vidaković et al. 2020). On the contrary, some studies indicate that in the context of a changing climate, greater attention should be given to the potentially positive role of non-native, climate-adapted, aesthetically pleasing species in urban planting schemes, as these could be well-received by the public (Hoyle et al. 2017).

Among the non-native taxa in the researched parks of Skopje, only one is invasive, and it was recorded in only one park, Woman-Warrior Park. It is well known that invasive plant species represent one of the major threats to global biodiversity, including urban biodiversity (Francis and Chadwick 2015, Williams et al. 2015, Kaushik et al. 2022). These species often act as pioneer species in different landscapes, are tolerant to disturbances, climatic conditions, and climate change, and have high competitive potential, which results in the loss of native flora (Kaushik et al. 2022). However, in the researched urban parks in Skopje, we can conclude that the situation is under control, and there is currently no threat posed by invasive species to urban plant biodiversity. The presence of only one invasive species in only one of the researched parks, with just five trees in total, is completely insignificant. In general, in urban parks like the researched ones, which are consistently managed through planning and maintenance, with no larger areas in a typical landscape style, the probability of invasive species occupying the space is very low. Nevertheless, in the future, special attention is recommended when introducing new woody taxa to ensure they do not possess invasive characteristics (Burton et al. 2005, Fuller et al. 2007, Kowarik 2011, Trentanovi et al. 2013, Wood et al. 2018).

Most of the native trees in the parks are older, indicating a decline in the use of native woody plants in urban green areas compared to the past, and an increasing use of non-native and exotic species in recent times. The oldest and largest trees were found in Woman-Warrior Park, where the largest number of native trees were planted during the construction of the park in the early 1970s. These species include *Pinus nigra* J.F.Arnold, *Platanus orientalis* L., *Betula pendula* Roth, *Tilia tomentosa* Moench, *Pinus sylvestris* L. and *Quercus robur* L. Specifically, the most striking specimens are those of the genus *Platanus* L., with an average diameter at breast height (DBH) of 61 cm. Notably dominant is one specimen of *Platanus orientalis*, with a remarkable DBH of 112 cm, along with three other trees measuring 96 cm. These four trees are believed to have been part of the area even before the park's construction. Generally, such old and large trees are keystone structures in urban parks and they are recognized for their biodiversity values (Jonsell 2004, Stagoll et al. 2012, Zebec et al. 2014) and for their ecological, historical and sociocultural importance (Tyrväinen et al. 2005, Poljak et al. 2011, Nolan et al. 2020). The other two parks are relatively new (since 2012), and they lack such old and large trees. Most of the trees in the other two studied parks have an average diameter of less than 30 cm.

The diversity of woody taxa in the researched parks was also analyzed using the biodiversity indices. The Shannon index values obtained for the researched parks indicate that none of the parks fall into the category of extraordinary biodiversity, which is defined by a value equal to or higher than 4 (Magurran 2003). In fact, Airplane Park has a particularly low Shannon index value of 1.30, which is even below the usual range of 1.5-3.5 (Shannon 1948). This was also confirmed by the Berger-Parker index, where values closer to 0 correspond to higher diversity, and a value of 1 indicates a monoculture (Berger and Parker 1970). Airplane Park had a value slightly above 0.9, indicating that it is very close to being a monoculture. The park is characterized by a high abundance of the following taxa: *Platanus* × *hispanica* Mill. ex Münchh., *Platanus orientalis* and *Prunus serrulata* 'Kanzan'. In addition, the values of the Simpson index indicated a highly homogeneous distribution of woody plant taxa, especially in two parks: Macedonia 1 Park and Woman-Warrior Park. Finally, the similarity between the researched parks was determined using the Sørensen beta index. According to the rule that values closer to 1 correspond to greater similarity in plant composition (Sørensen 1948), it can be concluded that there is a lack of significant similarity among the parks. From a biodiversity perspective, parks with a diverse plant composition are more beneficial than those with uniform plant components, which is why the analysis of beta indices for different habitats/parks is of great importance (Lakičević et al. 2022). Therefore, although the alpha indices suggest a lower to moderate diversity of woody taxa in the researched parks, the beta index suggest significant differences between the parks in terms of the presence of woody taxa.

CONCLUSIONS

Biodiversity studies are of great importance for raising awareness about nature preservation in the urban environment and improving urban life. In this study of three parks in the city of Skopje, a total of 90 different woody plant taxa were identified, which is somewhat lower compared to some other cities in Europe. Generally speaking, the surveyed parks have a significantly higher number of deciduous taxa compared to evergreen taxa, and a significantly higher number of non-native taxa compared to native taxa. Overall, the interrelated values of the calculated alpha indices contribute to a low level of species richness across the studied parks. While the values of the alpha indices indicate a negative impact on biodiversity, the Sørensen beta index reveals a positive perspective, highlighting a lack of significant similarity among the researched parks.

Since none of the parks is characterized by great biodiversity, the recommendations emphasize the need to enhance the biodiversity of woody plants in Skopje and to monitor it continuously. Biodiversity considerations should be integrated into the process of planning and landscape designing of urban parks, as well as in their maintenance, including the regular replacement of plants. Finally, this research can inform future studies by comparing biodiversity across parks and different time periods in the territory of Skopje, providing guidance for urban planners and landscape designers. Regular monitoring of woody plant diversity in urban parks should be established as a standard practice, as it is essential for understanding the actual situation and enabling timely interventions.

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