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Assessing the conservation value of cemeteries to urban biota worldwide

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Abstract

Cemeteries are key urban green spaces with multifaceted societal and ecological importance. Their biodiversity is shaped by unique environmental and cultural factors. They can potentially protect rare and endangered species, yet their conservation value compared with other urban green spaces remains largely unexplored. We sought to fill this gap by systematically reviewing literature to investigate the conservation value of cemeteries relative to other urban green spaces (botanical gardens, institutional premises, natural remnants, and parks) by comparing species richness and proportions of native and unique species. We analyzed data from 70 papers covering 50 cities in 27 countries with linear and binomial mixed-effects models at both site and city level. Cemetery conservation value was similar to urban parks, except for the proportion of unique species, for which parks had significantly higher proportions (21.9% vs. 14.2%, $p < 0.001$). Cemeteries hosted slightly higher proportions of native species at the city level than botanical gardens (99.7% vs. 99.6%, $p < 0.001$) and institutional green spaces (96.3% vs. 94.1%, $p = 0.034$) and proportions comparable to parks and natural remnants ($p > 0.05$). They also had similar or higher values than institutional premises in species richness and unique species proportions ($p > 0.05$) and a higher site-level proportion of native species ($p < 0.001$). In contrast, species richness (slopes = −0.11 and −0.25, respectively) and unique species proportions (4.4% and 6.9%, respectively, $p < 0.001$ for both) were lower in cemeteries than in remnants of natural areas and in botanical gardens. The conservation value of cemeteries and parks was similar for animals, but parks had a higher value for plants. Overall, cemeteries were generally at least as valuable as some other green spaces for urban biodiversity and mostly native biota. Their religious and cultural significance suggests they will remain intact in the long term; thus, it is essential to prioritize and further promote their biodiversity in conservation and sustainable urban design plans.

KEYWORDS
biodiversity, conservation biology, graveyards, macroecology, sacred sites, urban green spaces, urban wildlife

INTRODUCTION

Cemeteries are an important component of urban landscapes. They are multidimensional environments of cultural, spiritual, and historical importance and ecological relevance (Barrett & Barrett, 2001; Kowarik et al., 2016; Sallay et al., 2022; Uslu, 2010). In some countries, they function not only as a place to commemorate the deceased, but also as multifunctional spaces (Długoński et al., 2022; Grabalov & Nordh, 2022; Puplampo & Boafo, 2021). For example, in Berlin (Germany), the most prevalent reason to visit cemeteries seems to be to experience nature and more specifically to watch and hear wildlife (Straka et al., 2022). However, the extent to which the perception of cemeteries as multifunctional spaces is accepted varies across ethnic and cultural backgrounds (Nordh et al., 2023). Many cemeteries were originally located on the outskirts of settlements, but processes of urban sprawl have swallowed them up and turned them into island-like patches of green in the gray built urban area. Sometimes cemeteries are the sole open space in an urban area (Kowarik, 2020). Because most cemeteries contain trees, they have a positive impact on the urban environment by reducing temperatures, increasing humidity, cleaning the air of pollution and dust, and producing oxygen (Laske, 1994). At the same time, they can be a source of soil and groundwater pollution if not well planned and maintained (Franco et al., 2022; Leonard, 2022; Uslu et al., 2009).

It has long been claimed that investigating the contribution and importance of cemeteries to nature conservation is of great scientific and practical significance (Barrett & Barrett, 2001; McBarron et al., 1988; McPherson & Nilon, 1987). In many places and cultures, cemeteries are considered a permanent land use and are at a much lower risk of being demolished, decommissioned, or built over due to their symbolism and sacred status (Uslu, 2010). In some religions (e.g., Islam and Judaism), it is strictly forbidden to exhume graves and reuse the land. This gives cemeteries a special status in urban development plans: they are more likely to survive urban densification processes and remain important open spaces in the future. However, in some parts of the world (e.g., Central Europe and East Asia), the situation is different. Changes in burial preferences, a growing demand for urban space, attempts to diminish their negative environmental impacts (e.g., water pollution), and a loss of connection to the buried as a result of historical population shifts have diminished the use of urban burial space and accelerated the decommissioning of old cemeteries in some countries (Kong, 2012; Myślińska et al., 2021). A good example of this has been the conversion of cemeteries into parks following World War II and its consequential border changes and population shifts (e.g., in areas annexed by Poland from Germany) (Myślińska et al., 2021). Still, public acceptance of cemetery land-use changes is not ubiquitous even in these regions (Huang, 2007; Klingemann, 2022), and the ecological consequences of such processes are not yet well understood (Ghosh et al., 2019; Massas et al., 2018; Myślińska et al., 2021).

Cemeteries have several unique characteristics that differentiate them from other urban green spaces (Barrett & Barrett, 2001; Laske, 1994; Löki, Molnár, et al., 2019). They are often among the oldest and most prevalent open spaces in a city. Their landscape design, abiotic structure, and the level to which they support biodiversity in their area are influenced by the economic capacity and social considerations of the bodies that govern them (Quinton, Duinker, et al., 2020). Religious and cultural restrictions and traditions (e.g., differences in burial traditions and types of memorial elements used, the symbolic meaning of certain plants) seem to affect both manager and visitor activities and sometimes play a role in shaping biodiversity in cemeteries and the ecosystem services they provide (Caliskan & Aktağ, 2019; Dafni et al., 2006; De Lacy & Shackleton, 2017a, 2017b; Molnár, Takács, et al., 2017). Due to their historical development, social role, and cultural connotations, urban burial sites are often isolated by walls from densely built surroundings and the disturbances (e.g., car fumes, noise, hectic human traffic) they introduce. Cemeteries are not only less crowded with visitors than other comparable urban green spaces, they are also generally quieter. During the day, visitors of cemeteries are usually sensitive and respectful to the sacred status of the site and other visitors. At night, human visitors are largely absent, if the gates to the site are open at all. In some cultures, visitors also refrain much more than in other places from littering, out of respect for the site. In addition to reduced noise and litter, there are few to no artificial nightlights in cemeteries, and sites that have a dense canopy cover in parts or across the whole area are also shaded and darker during the day. Another important feature of cemeteries is a special type of soil named *necrosols* (Sobocka, 2004). This type of soil is often rich in organic matter and therefore nutrients due to the decomposing bodies and coffins and the recurrent digging. Necrosol characterizes the burial grounds more than other parts of cemeteries that are not used for burial, which creates a mosaic of soils with diverse chemical, physical, and biological profiles in a single site (Całkosiński et al., 2015; Charzyński et al., 2011; Majgier & Rahmonov, 2013). The diversity of microhabitats in cemeteries is not solely a consequence of necrosols. Traditional uses (e.g., ornamental planting, tombstone designs) also significantly contribute to this mosaic of environmental features (Löki et al., 2020). A large diversity of uses and land-cover types in a relatively small area, which likely creates a diversity of microhabitats and promotes biodiversity (Stein et al., 2014), thus seems to characterize cemeteries in general (Halda et al., 2020; Kowarik et al., 2016).

For all these reasons, cemeteries are thought to maintain a relatively high level of biodiversity, serve as urban sanctuaries for rare and endangered species, and be of high conservation value (Löki et al., 2015; Löki, Deák, et al., 2019; Löki, Molnár, et al., 2019; Lussenhop, 1977; Molnár, Nagy, et al., 2017; Molnár, Takács, et al., 2017). The conservation value of cemeteries in this context refers to the extent to which they support and protect biodiversity (Capmourteres & Anand, 2016). Generally, sacred natural sites, which are patches of landscape with spiritual significance to Indigenous people in a larger, often modified landscape, tend to have a positive effect on biodiversity conservation across multiple scales (Zannini et al., 2021), but little research in this regard has been dedicated to urban sacred sites to date (Jackson & Ormsby, 2017). Results of biodiversity surveys in urban cemeteries around the world are inconsistent with regard to the distinctiveness of their biota (Buchholz et al., 2016; Čanády & Mošanský, 2017; Örstan, 2004; cf. Fekete et al., 2019; Frosch et al., 2016; Shevchenko & Kolodochka, 2014). Furthermore, it is unclear how the conservation value of cemeteries compares with that of other types of urban green spaces, particularly parks, because urban biodiversity studies have tended to combine these two types of green spaces, thereby overlooking potentially meaningful differences (Pinho et al., 2021). Few studies have directly addressed this question, and the few that have show inconsistent patterns. For example, comparing biodiversity in cemeteries and urban parks revealed different patterns among countries (Morelli et al., 2018; Tryjanowski et al., 2017) and cities (Baldock et al., 2019), which suggests that patterns may vary at different spatial scales and that understanding of this issue is still limited. These studies were conducted at regional scales, and whether patterns at the global scale are similar or more consistent is unclear because no such empirical evaluation of this issue has been attempted.

We addressed this knowledge gap by investigating how the conservation value of cemeteries around the world, in terms of biotic richness, nativity, and uniqueness, compares with other urban green spaces (botanical gardens, institutional premises, parks, and remnants of natural areas). We considered different biodiversity metrics, taxonomic groups, and degrees of management. The goals of management can vary greatly among types of green spaces. Cemeteries are typically managed with a focus on maintaining the appearance and upkeep of the gravesites and memorials; they secondarily provide habitat for wildlife and preserve urban greenery.

Typically, cemeteries exhibit a mixture of unmanaged and managed vegetation that in many cases bares spiritual symbolism (e.g., Dafni et al., 2006), fostering a diverse array of plant and animal species adapted to semi-managed landscapes. In contrast, botanical gardens are typically managed with a focus on horticulture and conservation. They are designed to showcase a wide range of plant species from different regions of the world and are often used for research, education, and conservation. This typically fosters a rich diversity of microhabitats and plants, which in turn may attract a diversity of pollinators or other animal species. Institutional premises (e.g., university campuses, yards of governmental buildings) are typically designed and managed with a focus on functionality, such as providing a pleasant and attractive outdoors space for their workers and visitors, rather than environmental or conservation purposes. Aesthetics is often considered in the design and maintenance of the grounds; therefore, ornamental plants are often found in such areas. Urban parks are managed with a focus on providing recreational opportunities and aesthetic value and preserving green space; a specific focus on conservation varies depending on the park. For their anthropogenic-focused purposes (e.g., aesthetic values), they often encompass a variety of vegetation types, water features, and open spaces, which create a diversity of microhabitats for wildlife. Finally, management of urban natural remnants focuses on preserving and protecting the natural ecosystem and biodiversity. As patches of preexisting natural land cover in urban areas, they often harbor relict native vegetation and wildlife, frequently reflecting varying degrees of ecological integrity and providing refuges for native flora and fauna amid urbanization pressures. The intensity of site management is one of the most important factors in determining patterns of species richness in cities (Aguilera et al., 2019; Aronson et al., 2017; Beninde et al., 2015). Overall, cemeteries are thought to have management intensity similar to urban parks and institutional premises, and all three of these green-space types are more intensively managed than natural remnants and less managed than botanical gardens (Aronson et al., 2017; Quinton & Duinker, 2019). We therefore expected an intermediate level of biodiversity in cemeteries relative to the other types of urban green spaces.

METHODS

Data collection

We conducted a systematic literature survey in line with the PRISMA 2020 framework (Page et al., 2021) (Appendix S1). We searched for studies in the Web of Science (latest search on 28 October 2021) and in Google Scholar (latest search on 1 February 2022) with the following search terms: "*species richness*" AND (*urban** OR "*city*") AND (*cemeter** OR "*grave*" OR "*urban sacred*"). We replaced "*species richness*" with "*species diversity*" and "*biodiversity*" and repeated the searches. In Google Scholar, we used translations of the English search terms to search for papers in Spanish and German. We processed the first 10 pages of results in each search. For the Web of Science search, we included all returned publications for further screening.

The complete search process yielded 591 papers. We removed irrelevant papers based on an examination of the title, abstract, and keywords of each paper, which left 180 papers with potentially relevant data. We searched for studies that provided information on species diversity in at least one cemetery site and one other green space site in the same city that was a botanical garden, institutional premise, natural area remnant, or park. We focused on these four site types because they represented well a gradient of management intensity, were the most commonly studied and had sufficient, comparable data. Data for the cemetery and the other site could come from two different papers, but both papers had to have at least one shared author and similar sampling methods. This was to assure that the sampling of a certain taxon in a certain city was methodologically similar. Thus, in each specific instance, when collecting data for a particular taxon in a specific city, we included only data that were collected using the same methodology. Because we focused on comparing green spaces in individual cities for a given taxon, rather than making comparisons across different cities, our data set was methodologically consistent, ensuring that our comparisons would be valid and standardized within the scope of our study.

An additional obligatory condition for including data was that the area of the sampled site had to be reported or the site had to be easily traceable and its area measurable with a dedicated online tool (Daft Logic, n.d.). Of the 180 papers, we were able to extract adequate data (i.e., complying with all aforementioned requirements) from 22 papers. We searched for additional studies in the reference lists of identified studies and applied a targeted search for studies that had matching data on noncemetery green spaces in cities for which we had data for cemeteries. The full procedure yielded a set of 70 papers with relevant data on cemeteries and comparable matching data on other focal urban green spaces around the world. Of these papers, 41 had data for both cemeteries and other focal urban habitats, 12 had data on cemeteries only, and 17 papers had matching data for other urban green spaces only (Appendix S1). The literature survey was conducted by Y.I.

From these studies, we extracted data for animal, plant, and fungal diversity at two resolutions: sites and whole cities. In the site-level data set, each data point represented one taxon in one site. In the city-level data set, each data point represented the accumulated species richness of a single focal taxon across all sites of a particular type in a given city. The taxonomic group we documented was the lowest level reported in the study for the full set of sampled sites. In the case of botanical gardens, we included data on spontaneous species (i.e., those not planted there on purpose), whereas intentionally planted vascular plants were not considered because these do not represent the potential of botanical gardens for local plant diversity.

The conservation value of an area can be defined and quantified in multiple ways (Capmourteres & Anand, 2016). Generally, assessments of conservation values aim to inform and provide recommendations for conservation prioritization, based on the evaluation of different characteristics of a focal site, such as the diversity, rarity, uniqueness, endangerment, or nativity of its biota (Ratcliffe, 1977). We thus documented the following diversity data: species richness, native species richness, and unique species richness. With these data, we calculated the proportion of native species in each site and the proportions of native and unique species in a focal type of green space in a city. Accordingly, we only included in the city-level data set studies that reported site-specific species lists, site-type-specific species lists for each site, or the number of species unique to each site type for the entire city. To count the unique species, we compared in each study the inventory lists of species reported from each site type relevant for our study with those of all other types reported there, including those we did not document for our study (e.g., allotments, residential gardens, and golf courses).

Analyses

We used a linear mixed-effect model to assess differences in species richness between cemeteries and other site types with area and type of site as fixed effects and the city and taxon (as recorded) as random effects. To test for differences between cemeteries and other focal sites in the proportion of native species (both at site and city level) and proportion of unique species, we used a binomial mixed-effect model with the same effects as for species richness, except for area, and weighing by species richness. For the linear mixed-effects models, we used the function lmer, and for the binomial models, the function glmer, both from the lme4 package in R (Bates et al., 2015). We ran each set of the aforementioned four mixed-effect models for 6 binary comparisons of cemeteries with other focal sites: against each of the four other site types for all taxa combined and for plants and animals separately for the comparison between cemeteries and urban parks. For other site types, sample size was insufficient to perform separate analyses at the level of animals and plants. We transformed species richness and area to the $\log_{10}$ in all models to reduce heteroscedasticity in the residuals and linearize the power law of the species–area relationship (Connor & McCoy, 1979; Matthews et al., 2016).

RESULTS

We collected data from 50 cities in 27 countries, representing all inhabited continents (Figure 1) (full data sets are in Appendix S2). At the site scale, the average area per site included was largest for natural remnants (mean = 62.28 ha, $n = 26$), followed by institutional premises (31.99 ha, $n = 20$), parks (31.66 ha, $n = 174$), cemeteries (22.18 ha, $n = 155$), and botanical gardens (21.83 ha, $n = 13$). At the city level, the average number of sampled sites per city was highest for cemeteries (6.03), followed by natural remnants (5.93), parks (5.89), institutional premises (3.71), and botanical gardens (1.54). The average sampled area per city for a given site type was largest for parks (172.78 ha), followed by institutional premises (140.32 ha), natural remnants (127.08 ha), cemeteries (77.05 ha), and botanical gardens (27.36 ha).

Results of comparisons of cemeteries with other site types were inconsistent across the other site types and biodiversity metrics (Table 1; Appendices S3 & S4). Based on all four metrics, cemeteries were not more valuable than natural remnants and not less valuable than institutional premises. Except for the proportion of unique species, which was higher in parks than in cemeteries, the conservation value of these two site types was similar. Botanical gardens were more valuable than cemeteries based on all metrics except proportion of native species at the city level, which was higher in cemeteries. Cemeteries did not have a higher species richness or proportion of unique species than any of the other four site types. In contrast, the proportion of native species at the city level was never relatively lower in cemeteries.

The value of cemeteries compared with urban parks differed between plants and animals (Table 1; Appendix S5). For animals, cemeteries and parks did not differ significantly based on any biodiversity metric. For plants, all indices, except for the proportion of native species at city level, were higher in parks. In cemeteries, a mean of 97% ($n = 118$) of animals and 46.6% ($n = 47$) of plants were native at the site level and 97.5% ($n = 29$) of animals and 50.9% ($n = 19$) of plants were native at the city level. In cemeteries, a mean of 18.9% ($n = 29$) of animals and 27.4% ($n = 19$) of plants were unique. In urban parks, a mean of 96.5% ($n = 141$) of animals and 57.4% ($n = 48$) of plants were native at the site level, and 97.3% ($n = 22$) of animals and 39.9% ($n = 9$) of plants were native at the city level. In parks, a mean of 16.0% ($n = 22$) of animals and 33.4% ($n = 9$) of plants were unique species. Our data set also revealed that the proportion of native species was higher in animals than in plants in all site types at the site and city levels, but the proportion of unique species was always higher in plants (Figure 2).

DISCUSSION

In comparison to other urban green spaces, our results did not support the idea that cemeteries have a relatively high biodiversity or that they are hotspots of urban biota, as some studies suggest (Buchholz et al., 2016; Čanády & Mošanský, 2017). However, our findings in this regard are actually

TABLE 1 Statistics for main effects from generalized linear mixed models for differences in biodiversity indices between cemeteries and botanical gardens, institutional premises, natural area remnants, and parks.[a]

Data set	Metric	Taxon	Site type	Estimate[b]	SE	t	p
Site	Species richness ($\log_{10}$-transformed)	All	Botanical gardens	−0.25	0.07	−3.79	<0.001
		All	Institutional premises	−0.01	0.05	−0.15	0.884
		All	Natural remnants	−0.11	0.04	−2.69	0.010
		All	Parks	−0.01	0.02	−0.56	0.575
		Plants	Parks	−0.19	0.05	−3.42	0.001
		Animals	Parks	0.03	0.02	1.44	0.150
	Proportion of native species[c]	All	Botanical gardens	0.71	0.12	−2.88	0.004
		All	Institutional premises	2.41	0.22	3.93	<0.001
		All	Natural remnants	0.86	0.10	−2.11	0.035
		All	Parks	0.81	0.09	−1.67	0.094
		Plants	Parks	0.70	0.12	−2.92	0.003
		Animals	Parks	1.07	0.13	0.49	0.623
City	Proportion of native species[c]	All	Botanical gardens	1.42	0.07	4.73	<0.001
		All	Institutional premises	1.61	0.22	2.11	0.034
		All	Natural remnants	0.91	0.10	−1.37	0.171
		All	Parks	0.87	0.11	−0.87	0.383
		Plants	Parks	0.86	0.13	−1.17	0.242
		Animals	Parks	1.07	0.25	0.26	0.795
	Proportion of unique species[c]	All	Botanical gardens	0.53	0.15	−4.31	<0.001
		All	Institutional premises	1.13	0.25	0.48	0.631
		All	Natural remnants	0.66	0.11	−4.70	<0.001
		All	Parks	0.59	0.11	−3.87	<0.001
		Plants	Parks	0.24	0.24	−5.99	<0.001
		Animals	Parks	0.96	0.13	−0.27	0.783

[a]Full statistics of all models are in Supporting Information Appendices.
[b]Significant positive estimate for species richness indicates value is higher in cemeteries.
[c]Estimate is odds ratios, and values between 0 and 1 indicate the ratio at which the proportion in cemeteries is lower, whereas values >1 indicate the extent to which the proportion in cemeteries is higher.

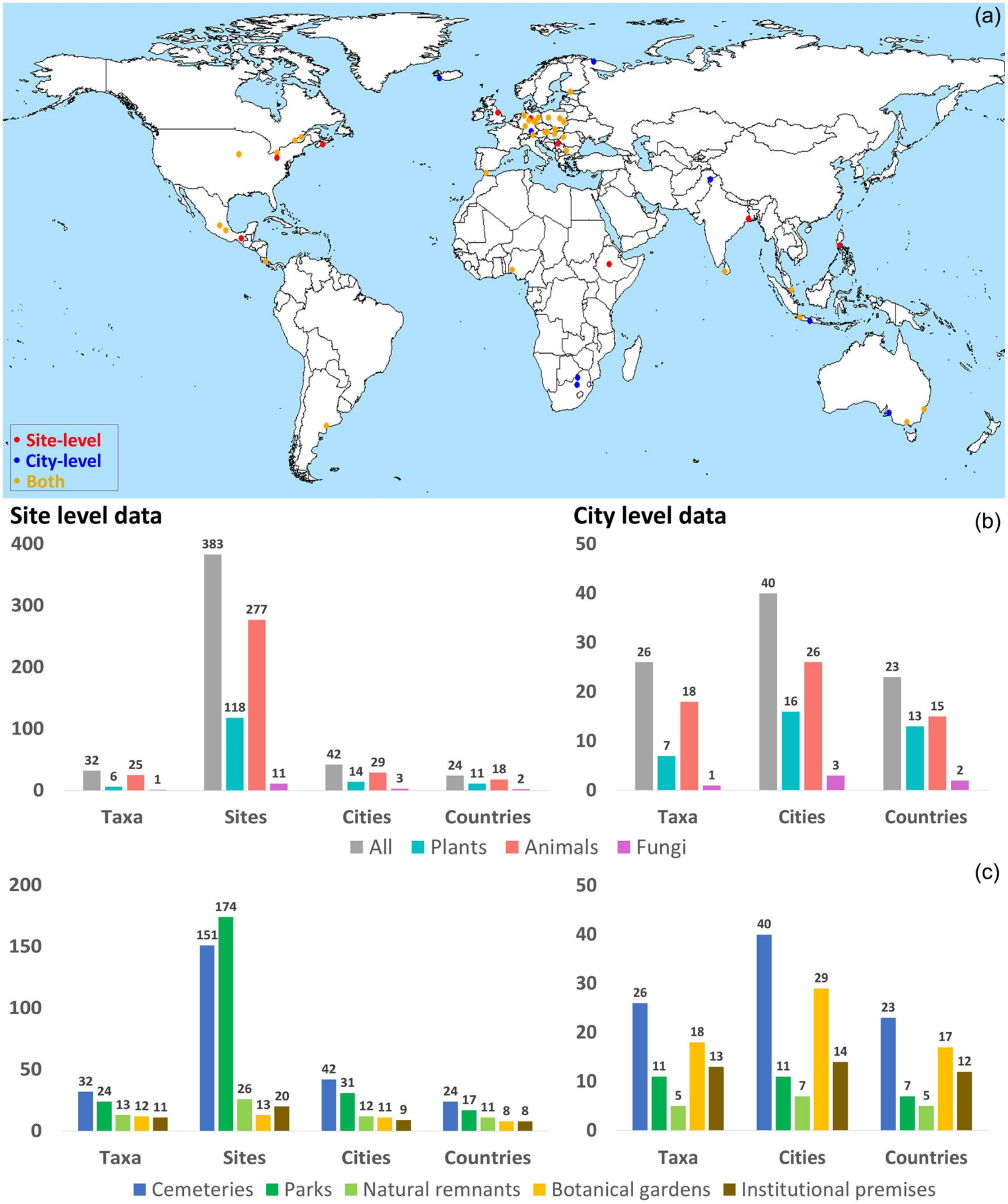

FIGURE 1 For a study of the conservation value of cemeteries relative to other types of urban green spaces at site and city levels: (a) number of taxa, sites, cities, and countries included by taxonomic group (plants, animals, fungi, and all combined) included; (b) sample sizes by taxonomic group; and (c) sample sizes by site type.

encouraging because if cemeteries are not richer than other green spaces, then the high numbers of species found in cemetery surveys implies that other green spaces in these cities may be at least as rich and maintain a higher biodiversity than is currently thought. This seems particularly true for urban natural remnants and likely for plants in urban green spaces. In the case of botanical gardens, their higher species richness relative to cemeteries probably results from their design, which aims to present a diversity of landscapes and microhabitats for the plants they house and from the impacts of planting a high diversity of species (which has clear conservation role on its own [Chen & Sun, 2018]), both of which provide an attractive environment for a variety of spontaneous plants, pollinators, and other wildlife. Urban natural remnants tended to have higher species richness than cemeteries, possibly because they have a longer history of preservation and are more likely to have undisturbed natural areas that can support a greater diversity of plant and animal species (but see Planchuelo et al., 2019). The

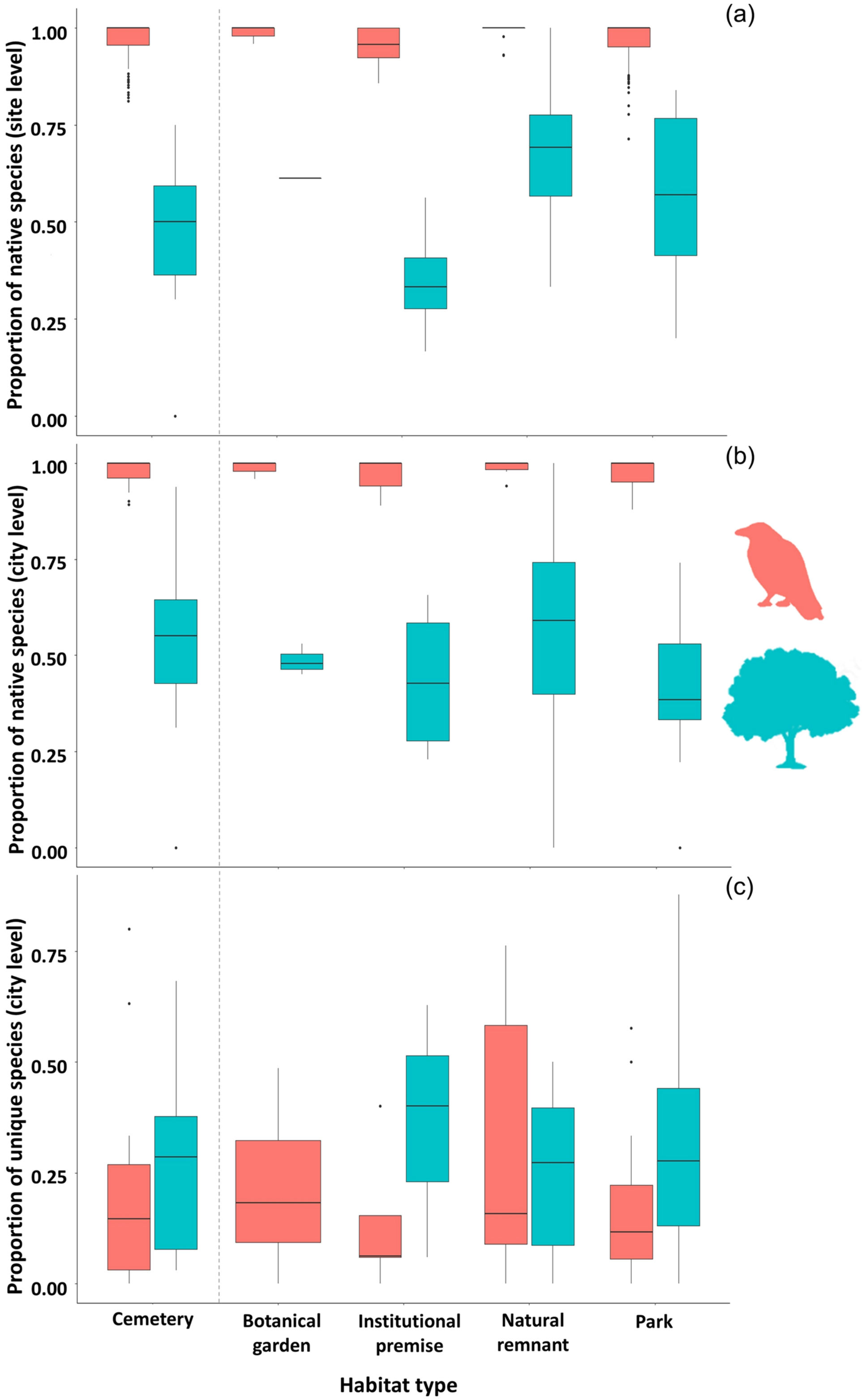

FIGURE 2 The proportion of (a) native species at site level, (b) native species at city level, and (c) unique species at the city level (all representing raw data, not accounting for differences across taxa or cities) for animals (red) and plants (turquoise) in each site type (horizontal lines, median; bar ends, interquartile range [IQR] [i.e., middle 50% of data]; whiskers, range within 1.5 IQR from the quartiles; points, outliers).

management of urban natural remnants is also more conservation oriented than that of cemeteries. In cemeteries, the planted species diversity is typically restricted by religious or cultural traditions. Furthermore, cemeteries are often small and isolated island-like systems (Itescu, 2019), which diminishes their ability to maintain species-rich assemblages at the site level (Beninde et al., 2015; Matthies et al., 2017).

Cemeteries provide a variety of resources and microhabitats that support a wide range of native biota. At the site level, cemeteries may not be as important for certain taxa because they may have other habitats available that provide similar resources and microhabitats. At the city level, however, cemeteries are often one of the most prevalent open areas, scattered in the urban space; thus, they become increasingly important for supporting biodiversity. The presence of cemeteries, similar to urban parks, can act as important corridors for wildlife movement and dispersal, connecting larger green spaces and allowing for gene flow among populations, which is key for the survival of biodiversity in fragmented ecosystems in general and in urban areas particularly (Beninde et al., 2015; Gilbert-Norton et al., 2010).

The lower proportion of unique species in cemeteries compared with natural remnants was expected considering cemeteries are more disturbed and that some urban-avoiding species can live only in these relict patches. However, it was surprising that the proportion was lower than that in urban parks and botanical gardens (Długoński et al., 2022; Savage et al., 2015). We suggest two possible explanations. First, cemeteries vary more than urban parks and botanical gardens within countries and cities (in appearance, landscaping, and management) due to geographical location, diversity in managing authorities and resources, and historical significance (Löki, Deák, et al., 2019; Löki, Molnár, et al., 2019). Cultural, religious, and historical legacies can affect management practices and the plants and wildlife presence (Caliskan & Aktağ, 2019; Molnár, Löki, et al., 2017). Environmental conditions, such as climate and soil, also play a role in shaping biodiversity in cemeteries (Betz & Lamp, 1992). Some cemeteries may be more naturalistic, others formal and manicured. This variability causes some cemeteries to have biota more similar to noncemetery green spaces in a city than to other cemeteries, which substantially diminishes the number of species that live only in cemeteries. Second, it could well be that the unique species at a city level are often non-native species, which were more common in the other site types, or species associated with landscapes and natural features that are not commonly found in cemeteries (e.g., ponds).

Cemeteries were more similar to areas with a moderate level of management intensity, and mostly to parks, supporting conclusions from previous studies that the conservation role of parks and cemeteries for urban biodiversity is similar (Leveau et al., 2022; Morelli et al., 2018). The intensity of management is considered an important factor for the biodiversity of urban green spaces (Aronson et al., 2017). However, our results suggest that the goals and foci of green space management may be more important in shaping relative conservation values than the intensity of management (although determining this requires further research). The most intensively and least intensively managed sites, botanical gardens and natural remnants, respectively, showed similar patterns relative to cemeteries. Although cemeteries prioritize peaceful and attractive environments for visitors, similar to urban parks and institutional premises, and conservation is only a secondary consideration in them, botanical gardens and natural remnants have a primary focus on conservation. Botanical gardens in many cases (although not all because some are not fully open to the public) prioritize showcasing diverse plant species and often include conservation-dedicated areas. Natural remnants are often protected areas with minimal management that have been left relatively undisturbed for a long period, allowing them to develop complex ecological relationships and maintain a higher level of biodiversity.

Although cemeteries generally preserve native species, their conservation value differs for different organisms. They were as important as urban parks for native animals, both at the site and city levels. However, their significance for native plants seemed lower in comparison to parks. A possible driver of this pattern is the impact of humans, who have more control over the flora in green spaces than the fauna, through selective planting strategies. In cemeteries, planted species are more similar across sites because there is a tendency to plant specific species with symbolic meanings or aesthetic function, whereas the choices for ornamental vegetation in different parks are more diverse. In this context, one important difference between animals and plants in urban green spaces is that plantings introduce many non-native plants into these areas, whereas the vast majority of animal species are native.

Interpreting our results with caution is important because our database has limitations. In particular, there are several spatial and taxonomic biases in the data (similar in the general sense but not in the details to Zannini et al. [2021]). First, taxonomically, most studies focused on vascular plants and birds and there was a lack of data on many other taxonomic groups (e.g., fishes, reptiles, amphibians, many invertebrate groups, nonvascular plants, and fungi). Second, vascular plants were surveyed and reported at much coarser taxonomic groupings than animals, which impeded fine-resolution analyses of plant patterns. Third, although all continents were represented in the data set, most data were from Europe (50% of the cities and 48% of the countries), potentially affecting the general patterns. Fourth, we could not obtain data for all studied site types in each city, and the number of sites representing specific types was uneven within and among cities. Additionally, the sample sizes for institutional premises and botanical gardens were not high (especially at the city level). Although we did our best to overcome these challenges through the application of methods designed to account for sample-size biases, these may still have had some influence on the observed patterns.

Our results certainly do not mean that cemeteries are not valuable. It could be that the value of cemeteries to urban conservation is simply not in being more diverse or hosting more unique species than other urban green spaces, but rather in other ways that we did not evaluate here (in addition to maintaining native assemblages). For example, they may provide refuges for endangered and rare species (Löki, Molnár, et al., 2019) or for species from biotopes that have severely diminished in the urban vicinity (Löki et al., 2020); favorable conditions for certain types of organisms with particular life styles (e.g., nocturnal fauna due to high level of shade and darkness from a high level of tree cover and few artificial lights [Straka et al., 2019]; soil-dwelling fauna due to their nutrient-rich soil [Butt et al., 2014] or saxicolous fauna benefiting from the concentration of tombstones in a relatively small area; saproxylic species that exploit deadwood, which is common especially in old cemeteries [De Zan et al., 2014; Kowarik et al., 2016]; tree-cavity users due to the relatively high number of old trees with cavities [Bovyn et al., 2019; Smith & Minor, 2019]); and protection from plant harvest (Molnár, Nagy, et al., 2017). Furthermore, cemeteries have a conservation role in that they contribute to human–nature relationships and the well-being of their visitors (Straka et al., 2022). We only compared cemeteries with other green spaces. If authorities were to consider closing a cemetery and building on it, this would necessitate a different comparison. Although we did not make such a comparison, it is safe to assume that cemeteries have a very high conservation value in cities relative to built areas and paved surfaces.

The results of assessing the conservation value of cemeteries compared with other green spaces through multiple biodiversity indices provides crucial knowledge for their conservation and management. Biodiversity is a multifaceted entity, and multifaceted entities should be assessed with sets of different metrics to evaluate them more rigorously (Itescu et al., 2020; Wolf et al., 2022). Our use of multiple metrics to determine the strengths and limitations of cemeteries as conservation sites allowed a more comprehensive and detailed examination, and our results may inform decisions on where to concentrate conservation efforts. Each metric reflected a different aspect of biodiversity, such as diversity, nativity, and uniqueness, and together they yielded a more complete picture of the conservation value of a site. Our results therefore indicated in this regard that considering their conservation strength in supporting more native assemblages in cities and their long-term permanence, cemeteries might remain the only pockets of stability, resilience, and perseverance for native urban biota in the face of future urban densification. This, however, would depend on how the landscape surrounding them changes, an aspect that should be considered in future development plans (Villaseñor & Escobar, 2019).

Cemeteries can offer a unique chance for conservation and restoration through sustainable management practices. By using native plants, removing non-native species, and implementing sustainable management practices, cemeteries can provide crucial habitat for endangered species. Several authors have outlined how cemetery management can become more environmentally friendly and lead to enhanced ecosystem services (Długozima & Kosiacka-Beck, 2020; McClymont & Sinnett, 2021; Quinton, Östberg, et al., 2020a). A holistic view, considering cultural and natural heritage, as well as traditional knowledge, is necessary for sustainable cemetery design and development (Długozima & Kosiacka-Beck, 2020; Molnár, Süveges, et al., 2017; Straka et al., 2022). Solutions, such as reducing pesticide and herbicide use, avoiding sealing paths and between-grave spaces, planting native vegetation and avoiding planting non-native species with invasion potential, and reducing mowing frequency, are available to enhance cemetery conservation value while preserving cultural and religious space (Długozima & Kosiacka-Beck, 2020; Laske, 1994; Quinton, Östberg, et al., 2020b).

Our results showed that cemeteries have fewer species and host fewer unique species than some other urban green spaces. However, they tended to house a higher proportion of native species. The conservation value varied based on the metric used, and cemeteries were similar to sites with moderate management. We also found that the conservation value of cemeteries differed for plants and animals. To fully realize the conservation potential of cemeteries, it is important to evaluate and understand the factors that shape their biota. Importantly, the current extent of available data on biodiversity in cemeteries is limited, and the patterns we detected, while providing interesting and potentially important insights, should be interpreted with caution. Future research should compare cemetery biodiversity, management practices, and visitor interactions with nature across different scales, as well as the impact of environmental and anthropological factors. We conclude that cemeteries are not more valuable than other green spaces for conserving urban biota, but they still offer important pockets of biodiversity in built surroundings, and actions should be taken to further enhance their conservation value. Given their long-term survival due to cultural and religious significance, cemeteries should receive special attention in conservation and sustainable urban design plans.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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