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Gardens of life: Multifunctional and ecosystem services of urban cemeteries in Central Europe and beyond—Historical, structural, planning, nature and heritage conservation aspects

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Cemeteries are often seen as monofunctional spaces for burial and mourning and, within the dynamically changing urban fabric, as a planning conundrum. Long periods of stability have also turned these untouched and hidden places into refugia for nature and wildlife. In booming and dense cities with high land use pressures and housing shortages, in particular, as the amount of burial ground needed per citizen decreases and burial cultures change, the cemetery has become a contested nature, as a simultaneous space of emotion, commerce and community. We revisited the diversity and ontogenesis of cemeteries, and the interactions with neighboring uses of the urban matrix. Our review demonstrates a wide range of different ecosystem services of urban cemeteries, beyond potential as hotspots of culture and biodiversity. We highlight their multifunctional character and the need for a holistic and trans-disciplinary evaluation using multistakeholder approaches to further develop cemeteries as a crucial element of sustainable urban landscapes.

KEYWORDS

burial ground, heritage conservation, habitat diversity, transformation, cemetery ecology, participation, urban planning, connectivity

Introduction

Due to their associations, and reflecting cultural changes in urban societies, burial grounds have always been special places within cities[1]. In Europe, their geographical removal from inner-city churchyards to the edges of urban settlements began in the 16th century, with the aim of reducing danger to public health. This also led to a semantic separation, "cemetery" instead of "churchyard" in the 19th century (Rugg 2000; Happe 2003). At the latest in the second half of the 19th century, cemetery planning started to focus on horticultural aesthetic design ("the garden on the grave"), and landscaped cemeteries were developed (von Zedler 1834; Happe 2003; Leisner 2005). The park cemeteries of the late 19th century combined different functions, including burial ground and public green space, thus anticipating the use of today's abandoned burial grounds (Leisner 2005). In North America, urban cemeteries of the 19th century were originally designed as public open spaces and as attractive burial and commemoration sites (Barrett and Barrett 2002; Harvey 2006; Möller 2015).

Although today cemeteries are often barren places within the urban matrix, and seen as monofunctional spaces for burial and mourning, with their amenity values widely neglected, some studies have recognized their provision of a wide range of ecosystem services, and their importance as a part of the urban green space (Barrett and Barrett 2002; Borgstrom et al., 2006; Harvey 2006; Andersson et al., 2007). Cemeteries are thus being rediscovered as elements of urban green structure during the last decade (Quinton and Duinker 2019; Rae 2021). Their environmental benefits are partially different from other urban green space (Quinton and Duinker 2019), as they are recognized as restorative spaces for urban dweller and, at the same time, as liminal spaces between clear positions and static forms, both in discourse and in people's everyday lives (Lai et al., 2020; Grabalov and Nordh 2022).

As urban cemeteries suffer lower disturbance frequencies and comprise more stable habitats than other green spaces, they can function as refugia for wildlife (Laske 1995; Loki et al., 2019). It was hypothesized that cemeteries in different religious contexts are promising areas for nature conservation compared to other urban land use types because their religious, historical, cultural and/or philosophical meanings protect their areas from destructive changes (Uslu et al., 2009). Other historical sites with protection status such as archeological parks and historical gardens function also as refuge for biodiversity (Ceschin et al., 2012; Tan et al., 2010; Capotorti et al., 2013; Caneva et al., 2018; Heneidy et al., 2022). Some surveys found that urban cemeteries did indeed have a higher number of plant species than similar sized parks or urban brownfields (Graf 1986), although others revealed a high proportion of non-native (Nowinska et al., 2020; Quinton et al., 2020; Walusiak and Krzton 2021) and also invasive plant species, which mainly entered from grave or hedge greeneries (Rutkovska et al., 2011) and could also spread to the surroundings (Walusiak and Krzton 2021). Horticultural history and the use of ornamentals for landscaping are widely recognized as driving the spread of exotic species from parks and gardens to neighboring land uses (Kowarik 2005; Butenschön and Säumel 2011), as non-native species regularly introduced as ornamentals can escape within cemeteries and to surroundings (Nowinska et al., 2020). Consequently, cemeteries have been addressed as model systems to study the interplay between cultural and ecological diversity (Barrett and Barrett 2002). Even so, 50 years have passed since the last published review on cemetery ecology (Thomas and Dixon 1973).

Recently, urban cemeteries have again drawn the attention of planners and local stakeholders in booming and dense cities with high land use pressures, and have become a contested nature as simultaneous space of emotion, commerce and community (Woodthorpe 2011; McClymont and Sinnett 2021; Grabalov and Nordh 2022). Two new challenges for their management need to be addressed. First, the amount of burial ground needed per citizen is changing. The burial ground area needed in Central European cities has declined sharply and, as a result of demographic changes (i.e., increasing life expectancy), disappearing religious traditions and new trends in the burial culture (e.g., cremation, private disposal of cremated remains), cemeteries are being abandoned. For example, in Berlin, Germany, a third of the cemetery areas (376 ha) will remain unused within the current decade (SenStadt 2006). In contrast, the North American "baby boomers" moving into higher mortality rates in the next decades is leading to a significant greater need for burial grounds, although the cremation rates there are also rising (Basmajian and Coutts 2010). Also in the US, an increasing demand for cemeteries close to residential areas has led to a relocation of cemeteries into neighbourhoods (Harvey 2006). Secondly, the multicultural society is leading to an increasing diversity of burial cultures (e.g., green burials, the foundation of Muslim cemeteries, and the renewal of Jewish burial traditions). The diversification of burial styles and the separation of cemetery areas to particular groups are expected to increase the need for space (Basmajian and Coutts 2010; Grabalov and Nordh 2022).

For both wildlife and heritage conservation, these changes can endanger a long-lasting habitat quality that was once protected by the original status as untouched areas. They can also, on the other hand, offer a chance to develop and strengthen cemeteries' ecosystem services, and to reduce the isolation of these habitats within the network of urban green structures.

1 In this paper, we do not focus on the antique necropolises, which were located outside the city and can also be important places for biodiversity and ecosystem services (e.g., Sadori et al., 2010; Haack 2017).

TABLE 1 Keywords relating to cemeteries and outcome-related key words for history, development, and characterisation, biodiversity as well as regulating, provisioning, habitat, and cultural services of cemeteries.

Search for	Keywords
Urban Cemetery	Cemetery (ies), graveyard, churchyard, burial, urban, city (ies)
History, development, and characterisation	history, cultural history, cultural meaning, design, historical plant use
Historical plant use, biodiversity and nature conservation	Diversity, biodiversity, species diversity, vegetation, flora, fauna, vegetation, tree(s), plant use, woody species, nature conservation
Regulating service	Climate, climate change, heat island, temperature, cooling, water regulation, water purification, storm water, air filtration, particulate deposition, carbon sequestration, noise reduction
Habitat service	Biodiversity maintenance, primary production, nutrient cycling, gene pool protection, nursery service
Cultural service	Culture, aesthetic, ethic, leisure, amenity, psychological, education, scientific, market value, spiritual, recreation, tourism, religious, sense of place

However, to provide trans-disciplinary knowledge, valuations and practical strategies to develop cemeteries as a crucial element of sustainable urban landscapes anchored in their neighborhoods, we need an evaluation of the broad range of ecosystem services cemeteries delivered.

The aim of this paper is 1) to briefly review the cultural diversity of cemeteries within the historical context, 2) to illustrate multifunctionality and ecosystem services provided by cemeteries, 3) to describe knowledge gaps that remain, and to highlight management challenges. We contribute to answering the following questions: How do cemeteries as historical elements of urban green interact with surrounding structures? How do cemeteries balance the partially conflicting demands as cultural heritage, habitat stability for flora and fauna, and functional adaptation in a dynamically changing city? In addition, we discuss current approaches to the redesign of cemeteries.

Materials and methods

We systematically screened peer-reviewed articles and scholarly books for research on history, development and characterisation of cemeteries and on historical plant use and biodiversity of cemeteries following the PRISMA Guidelines (Page et al., 2021). To review research related to human wellbeing in urban settings, we used the concept of ecosystem services (TEEB 2011). The Web of Science, Scopus and the catalogue of Deutsche Nationalbibliothek (German National Library) were searched with combinations of keywords relating to cemetery and the main categories of ecosystem services, i.e., regulating, habitat, cultural, and provisioning ecosystem services (for details on key words see Table 1).

We thus 1) identified studies that explicitly address functions of cemeteries and 2) we searched different disciplinary databases Web of Science and Scopus, both are standard databases for natural sciences, whereas humanities still work also with monographs that are listed in the large libraries such as the German National Library. The advanced keyword search in the German National Library (last updated February 2022) resulted in 1,969 references on urban cemeteries, 1,148 references on urban cemeteries and history, development and characterization, and three references urban cemeteries and historical plant use. The advanced keyword search in Web of knowledge and Scopus (last updated February 2022) resulted in 1,724 references related to Cemetery/cemeteries in the subject areas of environmental sciences ecology, geography and architecture, of which more than eighty percent were published during the last 2 decades (Table 2). Filtering the results to exclude papers focused on technical aspects not relevant to our study resulted in 399 articles from “ecology” and “environmental sciences”. We then screened the titles and abstracts of the remaining articles, eliminating those not related to our topic. In case of doubt, we retained the article. Subsequently, we eliminated articles lacking access to the full-text version and sent requests for the most relevant ones. Finally, we performed a full-text review of the remaining articles. We further included scholarly books and other grey literature found through cross-references. The data on plant species and parks or cemeteries used in this study are compiled from work already published.

Results

Overview of studies

Cemeteries have always played a role in the research agenda of humanities (Woodthorpe 2011). The number of publications on history, development, and characterisation of cemeteries has increased exponentially during the last decades (e.g., Schepper-Lambers 1992; Sieber 2018), although studies on historical plant use are scarce (Table 2). In the 80 s and 90 s, cemeteries appeared in increasing numbers of papers as subjects in environmental sciences, ecology, history, geography and architecture.

TABLE 2 Studies and scientific publications on cemeteries per year detected by the systematic keyword search (22.02.2022, see Table 1) within the German National Library and the Web of Science and Scopus.

Year	<1950	50s	60s	70s	80s	90s	2000s	2010s	Total
Search for	[in German National Library]								
Urban Cemetery/cemeteries in general	246	75	60	103	187	371	505	422	1969
Urban Cemetery/cemeteries and history, development, and characterisation	—	2	4	20	105	352	454	211	1,148
Cemetery/cemeteries and historical plant use						1	2	0	3
	[in ISI web of knowledge, Scopus]								
Cemetery/cemeteries in the subject areas of environmental sciences ecology, geography and architecture			1	9	63	87	191	1,373	1724
Cemetery/cemeteries in the subject areas of environmental sciences ecology				2	4	33	105	255	399
Cemetery/cemeteries and biodiversity, nature conservation, protection						1	14	41	66
Cemetery/cemeteries and ecosystem services							3	21	24
Cemetery/cemeteries and urban planning		1	1	1	3	11	55	127	199

Diversity of cemeteries

Burial costumes and related characteristics of cemeteries differ widely between cultures, religions and changed across time (e.g., Rugg 2000; Sörries 2003; Huang 2007; Uslu et al., 2009). Age, design, use history and localisation of cemeteries within the city strongly determined habitat characteristics and the interplay with adjacent land uses. Plant use and design of cemeteries resulted from the co-evolution of socio-economic and ecological systems, and can be addressed as socio-ecological constructs, as has been the case for gardens (Goddard et al., 2010). Different style epochs, landscape design fashions and management practices have repeatedly changed the character and functions of cemeteries (Sörries 2003; Cloke and Jones 2004).

Woody species are particularly involved in re-shaping processes of cemeteries, and can, in extreme cases, result in a "re-order by nature" after (partially) abandonment (Cloke and Jones 2004; Kowarik et al., 2016), with a higher proportion of native species (Nowinska et al., 2020). This entails numerous management challenges with regard to plant use and long-term care of trees (Quinton et al., 2020).

The plantation of native tree species (e.g., *Populus* spec. and *Tilia* spec.) that dominated Central European cemeteries till the 18th and the early 19th century (Happe 2003), was geometrically designed as a four field complex with tree lined alleys (Fischer 1996). In Hirschfeld's "Theory of Garden Art" (1785), cemeteries were seen as "melancholic gardens" and plant use was mainly oriented by a tree habitus, such as weeping *Betula pendula*, *Salix babylonica* or *Taxus bacata* and other dark leaved conifers. In contrast to Hirschfeld, Sckell (1825) recommended a broader set of deciduous mainly flourishing woody species (e.g., *Lonicera tartarica*, *Philadelphus coronarius*, *Syringa* spec., *Viburnum opulus* "Roseum"; Butenschön 2011). Later, in the second half of the 19th century, cemetery design adapted landscape garden principles following North American park cemeteries (e.g., Leisner 2005). The historical plant use pattern in cemeteries from the second half of the 19th century was dominated by the use of exotic species and cultivars (Table 3; Butenschön 2011). At the beginning 20th century, reform of cemetery garden art ("Friedhofreformbewegung") diversified cemetery habitat structures with a heterogeneous mosaic of different grave types lined by hedgerows (Schneider and Gröning 2000). A great variety of woody species resulted from the plantation of the private graves. Conifers became fashionable at the end of the 19th century, and between 30 and 50 percent of the woody species of cemeteries remaining from this epoch are evergreens (Butenschön 2011; Figure 1A).

The cemeteries thus reflect European exotic plant use fashion of the 19th and early 20th centuries, as is known from urban parks (Butenschön and Säumel 2011). This resulted from the increasing variety of plant material available, with new imports and cultivars during the European boom years of enthusiasm for botany and gardening (Wimmer 2001), and offered new design options for landscape architects (Schmidt 2004). There is evidence that long term abandonment of these cemeteries may reduce the dominance of exotic species and cultivars (Butenschön 2011; Nowinska et al., 2020). The encroachment of abandoned cemeteries in Berlin was dominated by escapees from primarily planted species, such as *Syringa vulgaris* hybrids (Graf 1986). In contrast to Europe, North American cemeteries frequently contain remnants of the original vegetation and sentinel (Barrett and Barrett 2002). Barrett and Barrett (2002) postulate that cemeteries, mainly those older than 100 years, manifest increasing biotic diversity and provide a large amount of

TABLE 3 Overview of types of cemeteries in Central Europe adapted from Graf (1986), Sörries (2003).

Types of cemeteries	Area (ha)	Location	Design	Plant use
Church yards of the middle age	<1	in the historic town centre nearby church	undesigned lawn with some (fruit) trees; very few woody species	*Tilia* species on the border; *Sempervivum tectorum* on graveyards wall; symbolic, medicinal plants
Alley-quarter cemeteries of the 18th century (e.g., Figure 1A)	2–5	outside the historic town centre, within urban extension of 19th century	with intersecting avenues, framing woody stands	*Tilia, Populus, Robinia*
Park cemeteries since the mid of 19th century (e.g., Figure 1B)	10–30	at the outskirts of the city		*Tilia*, *Castanea, Platanus, Betula Robinia*, conifers great variety
Forest cemeteries since 20th century (e.g., Figure 1C)	30–100	at the outskirts of the city	near-natural, woodland vegetation	often *Pinus*, remnants of the tree, shrub and partly also herb layer of the original forest vegetation

FIGURE 1
Impressions from different cemetery types in Central Europe (see Table 3): **(A)** Alley-Quarter Cemeteries Berlin Neukölln; **(B)** the greatest European Park Cemetery Hamburg Ohlsdorf and **(C)** the Forest Cemetery Stahnsdorf near Berlin. Sources: EdiCitNet, Paula Firmbach **(A)**; Sylvia Butenschön **(B, C)**.

ecosystem services due to the predominant use of native species and due to the existence of remnants of old "original" vegetation patches. Still, the Halifax cemeteries originating from the 18th to the 20th century are dominated by non-native species (e.g., *Acer platanoides*, *Tilia cordata*, *Ulmus glabra*, Quinton et al., 2020).

While the design of the individual grave and plant use has changed, profound analysis is lacking (Graf 1986). The meaning of plants was relevant until the middle of the 19th century, with some plants symbols of mourning, eternity, immortality, resurrection, purity, love, others were magical or medicinal, or strongly fragrant perennials. Since the reform of cemetery garden

art, however, plants have been selected primarily for their suitability as low-maintenance ground cover, semi-shade or Sun plants.

Are cemeteries permanent?

Cemeteries have been framed as a *planning conundrum*—a permanent land use within a dynamic land use system (Davies and Bennett 2016). Although they are often perceived as long-lasting places with a special emotional and religious significance, being affected by economic, political and generally practical changes, they too have been subject to major changes over time. This is particularly evident in the example of Berlin, where many historic cemeteries have been forced to be reduced in size, been apportioned or have been changed in other ways due to the Second World War, the division of the city, or road construction considerations. The graves of the famous philosophers Fichte and Hegel, for instance, were removed for the expansion of a street (Etzold and Türk 1993). Such developments took place not just in recent decades, they also occurred in the past, with cemeteries in the city area being abandoned and their contents rededicated to other purposes. This is how the old St. Hedwig's churchyard in Berlin came to serve as a storage place after its closure (Etzold and Türk 1993). A cemetery established at the beginning of the 19th century on today's Courbiereplatz was closed in 1879 after full occupancy had been reached and converted into a green space (Simon 2001). In East London in the last decades of the 19th century, after the 1884 Disused Burial Grounds Act, the Metropolitan Public Gardens Association converted disused burial grounds and cemeteries into publicly accessible green spaces and into playgrounds (Brown 2013). The dynamic nature of urban deathscape of Gdansk, which could be done for many other cities, maps different existence periods of cemeteries and diverse post-cemetery use types, often green structures but also housing, service and production (Puzdrakiewicz 2020).

Cemeteries within the urban matrix

Cemeteries, originally located at the fringes of cities on low-cost areas, near transportation corridors, were integrated into the urban fabric with city growth (Rugg 2000; Worpole 2003; Harvey 2006). Open space descriptive statistics show that cemeteries are usually smaller than parks or urban forests, and cover an area less than 10 ha (Rehackova and Pauditsova 2004). Nevertheless, they are a crucial part of scattered green spaces, which are likely to become more important for human recreation and climate regulation (Bowler et al., 2010; Nordh and Evensen 2018).

Compared to other types of urban green space, cemeteries exhibit several unique features, including long-lasting habitat stability, low use and disturbance frequency ("pointing towards eternity"; Grabalov and Nordh, 2022) and a high degree of isolation. Within the urban matrix, cemeteries function often as islands with a sharp, often walled, border. Whether this impedes or strongly reduces exchange of plant species (Nowinska et al., 2020) is unclear as data of possible ecological trap effects are missing (Löki et al., 2019). In addition, better analysis of the effects of the surroundings on the cemeteries is needed (Barrett and Barrett 2002), and the environmental impacts of cemeteries, such as ground water pollution, depend largely on the conditions in the surroundings (e.g., substrate, land relief, hydrogeological and weather conditions; Żychowski, 2012).

There is also the administrative ambiguity of cemeteries, which are recognized as part of the urban green but operated by owners (e.g., religious organisation) without strategic green infrastructure management (Kjoller 2012; Nordh and Evensen 2018). Cemeteries are thus normally less integrated into urban habitat networks and green infrastructure systems than parks and other green spaces, which have been subjected to habitat networks efforts of planners for a long time. Sympathetically managed green space networks are crucial for ecological connectivity, species and habitat conservation within the highly fragmented urban landscape to diminish isolation and sinks effects and foster ecologically functional urban landscapes (Andersson et al., 2007; Goddard et al., 2010). There is, however, evidence that cemeteries of small towns are better integrated in the green space system than previously expected (Jebavy 2009).

An important ecological impact of cemeteries is the formation of "Necrosols" when, in temperate climates, human corpses decompose during a resting time of between 15 and 25 years (Fiedler and Graw 2003). Depending on depth of burial and cemetery age, cemetery soils generally are wet and highly permeable and accumulate more total carbon, microbial biomass carbon, phosphorus and total nitrogen, larger amino acid and ammonium concentrations compared to background values, which is consistent with increasing respiration rates, net nitrogen mineralization and pH values (Hopkins et al., 2000; Charzyski et al., 2010). "Necrosols" are further characterized by the absence of natural horizons, by urban layers with sharp transitions, and large quantities of artefacts (Gerasimova et al., 2003; Sobocka 2004). The resulting patchiness of different soil types within cemeteries also determines habitat diversity and species composition, beyond design options.

Regulating services

The historical reasoning of the 18th and 19th centuries shows that the use of woody plants at cemeteries was primarily intended to control air pollution and to enhance urban sanitation, rather than being ornamental and symbolic (Happe 2003). A buffering and air-purifying effect of plants was also assumed to keep out the so-called "mephitic airs" and "miasmatic vapours" ("Theory of Miasma"; Steckner 1979; Happe 2003). The cultivation of

certain plants on burial grounds was therefore intended to serve to protect the living from the vapors of the deceased (Steckner 1979). The role of cemeteries as pollution and disease-vector sources was also the main focus of early environmental research on cemeteries (e.g., Pacheco et al., 1991; Omeara et al., 1992). Impacts on groundwater and soils are associated with high levels of bacterial pathogens, amino acids and other organic compounds originating from the decomposition of the buried bodies passing through the soil and into the groundwater (reviewed in Żychowski, 2012). This dis-service of potential groundwater pollution by cemeteries is more often analyzed than beneficial regulating services (Figure 3). Although cemeteries are partially monitored as potential sources of groundwater pollutants, several countries do not have appropriate legal regulations with regard to this problem (Żychowski, 2012). The increasing numbers of modern "green" or natural burial sites also require groundwater vulnerability assessment, as their impact on the environment is less well understood than those of crematoria or conventional cemeteries (Kim et al., 2008). As, in order to reduce these risks, cemeteries are usually built in low permeable soils away from anaerobic conditions (Pacheco et al., 1991; Spongberg and Becks 2020; Young et al., 2002, Żychowski, 2012), water purification services by soil filtering can be neglected (Hopkins et al., 2000; Charzynski et al., 2010, Żychowski, 2012).

The generally wet soils of cemeteries also increase evapotranspiration and enhance air cooling capacity (Hopkins et al., 2000; Charzynski et al., 2010, Żychowski, 2012). In the face of climate change, the function of cemeteries as cold and fresh air generation areas has gained increasing importance in mitigating the combined effects of urban heat island effects and global warming (Bowler et al., 2010; Onishi et al., 2010; Mathey et al., 2011). Cemeteries are regularly included in modelling approaches for urban climate regulations (Kazmierczak and Carter 2010). The higher green volume density of a mainly woody species in cemeteries and other small and scattered green spaces strengthen the potential cooling effect, and may be comparable to that of larger green spaces (Mathey et al., 2011; McClymont and Sinnett 2021).

Few studies have addressed directly regulating services of cemeteries (Liu and Zhao 2011; McClymont and Sinnett 2021). One initial study modelled the ecological benefits of a Chinese cemetery, including carbon storage and removal of key air pollutants, which are highly dependent on tree species, community structure, age and growth status (Liu and Zhao 2011). Green areas are generally known to improve air quality and public health, especially woody vegetation immobilises particulates (Escobedo et al., 2011). An early comparative study on and the exposure to traffic-related air pollution and health-effects found a significantly higher prevalence of chronic bronchitis, asthma, and several other symptoms for street cleaners compared to cemetery workers in Copenhagen (Denmark), thus indirectly providing evidence on air filtration potential of cemeteries (Raaschou-Nielsen et al., 2015).

Habitat services and biodiversity

Although cemeteries have been highlighted as guardians of "intact" habitat patches in both the urban and rural landscape (Löki et al., 2019), they also include intensively and extensively managed tree and shrub patches, lawns and meadows, small wetlands, creeks and ponds, tended flower beds, tombs, vacant lots with spontaneous vegetation, promenades, alleys and small paths, build-up structures like walls or pantheons. This patchwork of different elements, ranging from more natural to highly managed areas, offers very diverse habitats. Moreover, as urban cemeteries are regularly not equipped with electric lighting and are closed at night, night in them is still dark and calm (Gerhardt 2007), so might support wildlife, although the effect of light and noise pollution on biodiversity remains widely understudied in general (Hölker et al., 2021).

Undoubtedly, cemeteries harbor a high number of species, a great proportion of rare or endangered species so have been considered "Gardens of life" (Graf 1986; Laske 1995; Reidl 1999; Löki et al., 2019; Nowinska et al., 2020). Consequently, cemeteries can play a key role in species conservation (Verschurren et al., 2010; Löki et al., 2019), and their increasing area increases the number of different habitats (Reidl 1999; Nowinska et al., 2020), and of plant (Lange and Schäfer 2001; Nowinska et al., 2020) and bird species (Morelli et al., 2018). The increasing age of the cemetery increases the number of rare and endangered species there (Tillich 2013; Nowinska et al., 2020), and the surroundings shape habitat function for plant species (Graf 1986; Nowinska et al., 2020), for breeding bird abundance (Abs et al., 2005).

Species composition of cemeteries in Stockholm, Sweden, differed from parks and allotment gardens mainly due to a few less-abundant species, but not in the overall community structure; and the assemblage of different functional groups was related to differing management practices (e.g., organic gardening practises might favour decomposers and insectivorous birds, Andersson et al., 2007).

A higher number of higher plant and fern species were reported in cemeteries than in parks of the same size (Graf 1986; Figure 2A). Analogous to parks, brownfields and gardens, size was positively related to plant species richness, which in turn may be positively correlated to land cover heterogenity and avian species (Goddard et al., 2010). A meta-analysis revealed a higher number of species per area only for a subsample of small cemeteries and parks (<1ha, N = 36; Figure 2C), but not for larger parks (0.1–200 ha, N = 129; Figure 2B). Diversity enrichment effects of cemetery habitats designed in small sections enhanced plant diversity mainly at small scale. Consistently, small to medium sized cemeteries harbored twice as many endangered and rare species than other same sized green spaces, and functioned frequently as refugia for indigenous species in inner city neigborhoods (Graf 1986). The diversity of large cemeteries was similar to parks.

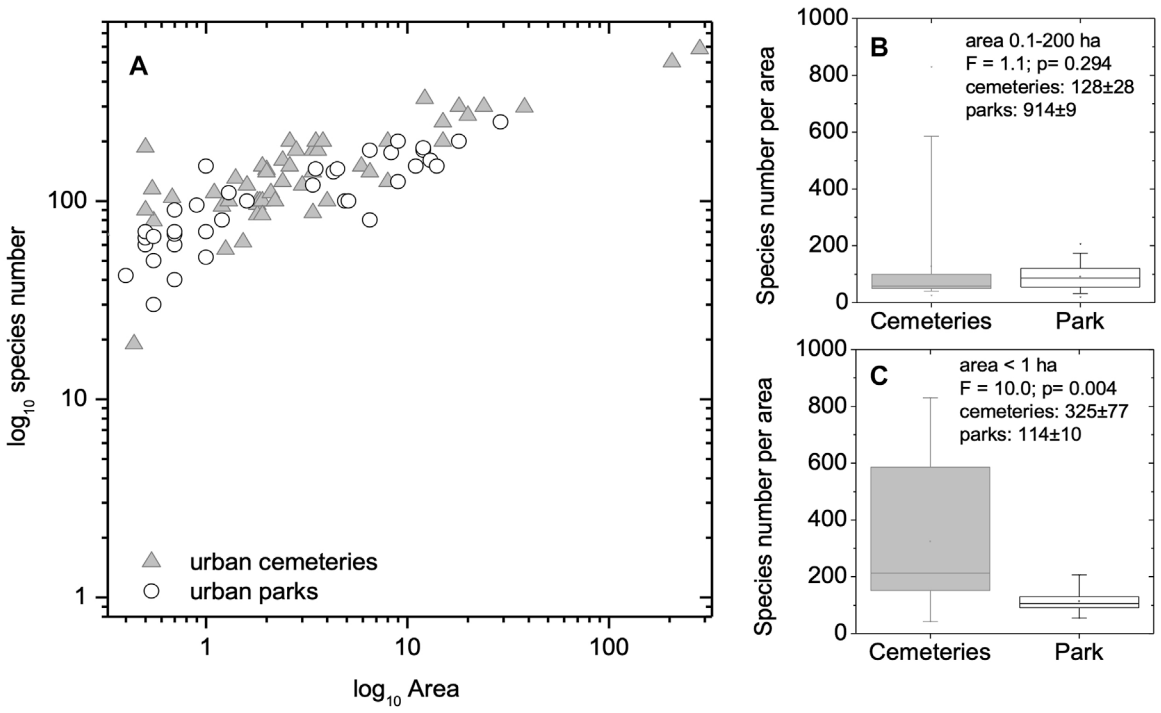

FIGURE 2
(A) Relationship between plant species number and area of Central European cemeteries and parks compiled from floristic studies of 42 cemeteries and 35 parks (Sources: Kunick 1978 and Kunick 1990, Graf 1986). These studies mapped presence/absence of the plant species during two vegetation periods (Graf 1986). Comparison of number of species per area for all cemeteries and parks with an area between 0.1 and 200 ha **(B)** and for a subsample of small cemeteries and parks with an area below 1 ha **(C)**.

However, biodiversity studies were available only for a minority of urban cemeteries, and studies often included only a subset of species (Löki et al., 2019).

Number and types of habitats are strongly related to both types of cemeteries, and to their design and maintenance history (Cloke and Jones 2004). Cluster analysis of flora on urban cemeteries in Berlin demonstrated the role of cemetery's age, design and plant use on plant diversity (Graf 1986). The eternal resting time of Jewish cemeteries, which is different from Christianity, combined with a low disturbance frequency and extensive management, enhanced wildlife (Buchholz et al., 2016; Kowarik et al., 2016). The characteristic old ivy-covered tree stands of these cemeteries also included habitats for wetland species, which are rare in urban environments (i.e., *Salix aurita, Scutellaria galericulata* or *Juncus effusus*). In particular, partially abandoned cemeteries of the 19th century (i.e., allee quartier cemeteries) and extensively managed woodland cemeteries with remnants of pristine vegetation harbor higher diversity and more rare species (Graf 1986).

Historical plant use patterns, especially woody species, determine structures and habitats of cemeteries and burial grounds (Graf 1986; Butenschön 2011). Tree species, community structure, age and growth status of the trees influence provision of ecological benefits. A survey on urban trees and the history of urban tree planting in arctic and near-arctic cities (i.e., Murmansk in Russia, Nuuk in Greenland, and Reykjavik in Iceland) demonstrated that grave trees were the first trees to be introduced in these cities, mainly selected by a "trial and error" strategy (McBride and Douhovnikoff 2012). The number of tree species was low (i.e., 1–6 species per cemetery, *Acer pseudoplatanus*, *Betula pubescens* and *B. subarctica, Picea abies, Pinus sibirica, Salix caprea,* and *S. glauca* and *Sorbus aucuparia* (McBride and Douhovnikoff 2012). This contrasted sharply with cemeteries in cities in other climatic regions. At the Ohlsdorf cemetery in Hamburg, Germany, 450 woody species[2] were recorded (Westphal 2006; Schönfeld 2012). In New York

2 The foundation of this rich stock of woody species goes back to the first cemetery director Wilhelm Cordes (1840–1917). Only a few years after the foundation of the cemetery in 1877, he bought around 57,000 trees and shrubs that the James Booth and Sons nursery sold at a favorable price before it was closed down. "The joy and longing for nature entitle especially the big cities to design cemeteries as far as possible with trees. A quiet walk under the trees, a quiet bench [...] that is the general wish." (Wilhelm Cordes, 1914) Later the cemetery purchased additional plants, but also operated its own cultivation garden with 15 greenhouses for various flowers and shrubs.

City and Los Angeles, cemeteries with over 100 tree species were reported (Harpaz 2009). Arboretum-like designed cemeteries included a particularly high variety of woody species (e.g., Portland Lone Fir Cemetery, Harvey 2006). The multi-storey vertical community structure aided ecological benefit generation and the long lasting and sustainable development of the green-spaces (Liu and Zhao 2011). Consequently, cemeteries and parks are acknowledged as important habitats for the conservation of old trees in agricultural landscapes, with a higher proportion of champion trees found in cemeteries compared to other green spaces (Orlowski and Nowak 2007). This study also provided an impressive example, that of a northern white cedar surviving the huge devastation of green areas during and after the Second World War in a cemetery.

Spontaneously occurring and ruderal species establish only on abandoned grave stone areas, along pathways, on walls, at composting sites or storage areas, and consist of partially escaped ornamental species, fern, moss, lichen or nitrophilic species (Graf 1986; Nowinska et al., 2020). Gravestone areas can also harbor lichen and bryophyte communities depending on care intensity but are dominated by ground covering evergreens and conifers, frequently managed by individuals, constrained by guidelines, regulations, weed control measures and a small and seasonally changing set of planted species (Nowinska et al., 2020). Several studies on historic tombstones from different centuries observed a hidden part of biodiversity such as epilithic lichenized fungi and moses, micromycetes and cyanobacteria, which are often primary colonizers of stone (e.g., Gorbushina et al., 2002; Cuzman et al., 2011; Caneva and Bartoli 2017; Grbic et al., 2017).

Meadows are mainly situated at representative and extensions of cemeteries or between graves (Graf 1986; Laske 1995). More extensively managed meadows can harbor a highly diverse flora and fauna and serve as refugial habitat for red list species, though studies on this are scarce (Konic et al., 2021).

Some symbolic plants, old cultivars and medicinal plant species also remained as historical plant use relics (e.g., *Achillea ptarmica*, *Aquilegia vulgaris*, *Tanacetum parthenium*, *Calendula officinalis* or *Papaver somniferum, Aphanes inexspectata*, *Digitaria sanguinalis*, *Setaria pumila*, *Stachys arvensis*; Graf 1986). In addition, rare or endangered geophytes originating from different natural habitats (e.g., *Gagea* spec. or *Tulipa sylvestris,* orchids) have been reported at cemeteries (e.g., Tillich 2013; Buchholz et al., 2016; Kowarik et al., 2016; Löki et al., 2019; Konic et al., 2021).

Macromycetes are widely understudied in urban landscapes as well as in cemeteries, although fungi are important decomposers and strongly influence plant communities (but see Barrico et al., 2012; Schlecht and Säumel 2015). Fungi, ferns, moses and lichenes have been reported on cemeteries (e.g., Fortey 2000; Venne et al., 2016), though detailed studies are scarce (but see Fudali 2001; Grochowski, 2001). Moses and lichen at cemeteries were studied to control for habitat variability and pollution (e.g., Klos et al., 2008; Ciesielczuk et al., 2012).

Ornithology has long demonstrated the role of cemeteries as multifunctional habitat for birds in cities (e.g., Flade 1994; Abs et al., 2005; Tryjanowski et al., 2017; Čanády and Mošanský 2017; Morelli et al., 2018). Bird diversity increases with cemetery area, number of nesting sites, and forage opportunities. Larger cemeteries with a large-scale heterogeneity harbored a higher number of bird species than surrounding urban areas (Lussenhop 1977). A survey on Central European breeding bird species distribution among different urban land uses revealed a large crossover between key species of cemeteries, parks and gardens (Flade 1994). Urban cemeteries were also breeding grounds for highly endangered species. An example in the tropics: a cemetery in Manila (Indonesia) harbored a higher avian biodiversity including endemic and threatened species than parks (Vallejo et al., 2009). Bird species distribution depended on degree of urbanisation in cemeteries surroundings (Flade 1994). Composting sites were usually food sources for birds and, at the same time, habitat for many insects (Andersson et al., 2007).

Habitat diversity also favored herbivores, insectivores or seed dispersers and a higher total number of flowering plant species compared to parks favour pollinators (Andersson et al., 2007; Bates et al., 2011). Abundance and pollinator diversity of cemeteries were negatively associated with higher levels of urbanization (Bates et al., 2011). In Montreal and Quebec, Canada, wild bee abundance but not diversity was higher in community gardens and parks compared to cemeteries (Normandin et al., 2017). A high percentage of butterflies was reported on meadows and ruderal sites of cemeteries (Strobl and Könecke 1984). Studies on *Diptera* in flower vases with water demonstrated that the land use "cemetery" determined the species composition of the fly community more than the intensity of the urbanization in its surroundings, and urbanization level around a cemetery shaped some attributes of its *Diptera* community (Rubio et al., 2012). In addition, cemeteries in the tropics and subtropics are known to be favorable urban habitats for the proliferation of human disease vectors, and pathogenic *Diptera* species in cemeteries are well studied (Abe et al., 2005; Vezzani, 2007; Leisnham and Juliano 2009; Arunachalam et al., 2010). Entomofauna of cemeteries and especially collembola have been frequently studied in forensic science (e.g., Bourel et al., 2004; Merritt et al., 2007).

Cemeteries are parts of predicted corridors or stepping stones for gene flow in mammal populations between city parks in a heavily urbanized areas, for example, for small mammal populations in New York (Munshi-South 2012), and for coyotes in Boston, Massachusetts (Way and Eatough 2006). Small mammal species composition differed between gardens, cemeteries or urban woodland, with cemeteries harboring more wood mouses but less vole and shrews than allotment gardens (Baker et al., 2003). Bats, fox and hare have been reported from urban cemeteries (Graf 1986). However, studies on mammals and on reptilia in cemeteries are scarce (Tikhonova et al., 2002).

Cultural services

The purpose of cemeteries frequently extends beyond the need for a burial space, to being a religious and sacred place for permanence and pilgrimage, and a place for demonstrating civic pride that also provides recreational amenities. They thus possess multiple social and political meanings (Rugg 2000), and their design has high cultural significance and provides insights into society and culture (e.g., Veit and Nonestied 2008; Herman 2010). They are typical examples of heritage landscapes that are socially constructed and shaped by ritual involvement from the local community, and thus of peoples' memories create a sense of place rather than space (Worpole 2003).

Walls, hedges, ditches and other boundary structures of cemeteries serve primarily to create atmosphere, which can be experienced in the interior as a mythical space separated from the rest of the mostly secular world (Hasse 2005). Life and death grew more separated (Worpole 2003). The modern cemetery in the mid-nineteenth century especially captured the diversification and widening of dispositional techniques of institutions and, at the same time, integrated hygienic imperatives, aesthetic-moral registers and an array of educational-civic functions, generating a model milieu for the living (Johnson 2007). Analysis of grave inscriptions over the last century indicated that, just as death was becoming more and more marginalized, society appeared to be increasingly less accepting of the finite nature of life (Anderson et al., 2011).

Cemeteries are recognised as a cultural heritage of society. Many associations promote historic cemeteries and offer, for example, guided tours of cemeteries on the Open Monument Day (Finetti 1999; Sommer 2018). Graves of notable citizens are tourist attractions, but graves of non-notable citizens also function as emotional landscapes and demonstrate diverse cultural memories (Sörries 2009; Basmajian and Coutts 2010). The presence or absence of these individuals in the cemetery landscapes depends on different commemorative practices influenced by religion, culture, gender, status and age. Apart from prehistoric and imperial tombs in China, there is only one cemetery on the UNESCO World Heritage List, the Skogskyrkogarden in Stockholm, a representative of a park cemetery (Unesco World Heritage Convention 2022). The Central Cemetery in Ljubljana, Slovenia has had a European Heritage Label list since 2007 (Sörries 2009). Work is currently underway to include the Jewish cemetery Weißensee on the World Heritage List. In a society where dying and death have largely been marginalized, cemeteries become increasingly recognized as unique cultural heritages (v. Krosigk and Gotzmann, 2007), and, in Germany, cemetery culture has been "intangible cultural heritage" since 2020.

Traditional cemeteries and alternative burial grounds potentially improve a community's natural environment. Cemeteries have, for a long time, been recognized as open spaces. At present, many municipalities consider cemeteries part of their green infrastructure, and in some places, residents use cemeteries for recreation (Harvey 2006). A study from Oslo registered a wide set of activities within two cemeteries, where mostly adults visiting graves was just one activity among many others such as walking, biking, walking the dog, socializing or resting on benches (Evensen et al., 2017). This prompts discussion about the compatibility of diverse uses, and also of cemeteries as amenity spaces in a multicultural context, with the potential to stimulate intercultural and interreligious encounters (Swenson and Skar 2019). Cemeteries were also designed as an arboretum-like landscape used for historical plant identification, restoration and educational projects (e.g., Portland Lone Fir cemetery, Harvey 2006).

As cemeteries can also harbor (un)wanted heritage of previous communities, some necropolises have been closed and removed (e.g., Puzdrakiewicz 2020). If cemeteries are seen as an evolving cultural landscape, the preservation of historical urban burial grounds can be combined with the creation of open space by incorporating tradition into modern time-space (Cartier 1993; Huang 2007; Teather et al., 2007), perceived as a kind of in-between area of the private–public realm (Swensen and Brendalsmo 2018). The neighborhood shapes the development of residential areas and large clusters of allotments, cemeteries, or sports fields were estimated as relatively attractive for residential development, while forest, nature, and industrial areas became more attractive when present in small clusters (de Nijs and Pebesma 2010). A review of hedonic price studies of open space values for properties, including land characteristics, structural characteristics, neighborhood and environmental characteristics, underlined the importance of jointly examining multiple types of open space lands and carefully distinguishing among types of open space. Anderson and West (2006) found a positive relationship between house price and distance to cemeteries, though other cemeteries did not affect the sale prices of residential properties (Lutzenhiser and Netusil 2001; Neumann et al., 2009). The benefits of proximity to cemeteries depended on neighbourhood characteristics and location, and the amenity value of proximity to cemeteries falls as private lot size increases (Anderson and West, 2006).

Provisioning services

This category of ecosystem services comprises benefits that can be extracted from nature, such as food, timber, water, products from domesticated species or plants that can be used as medicines. It has been argued as unlikely that cemeteries could be used for food production (McClymont and Sinnett 2021), although the authors observed a small community orchard in one of the burial places studied. Urban fruit tree mappings revealed several fruit trees, edible herbs or mushrooms for foraging at cemeteries (Mundraub, 2022; Schlecht and Säumel 2015; Buchter-Weisbrodt, 2009). Urban wild food foraging discussed also mentions cemeteries as foraging locations (McLain et al.,

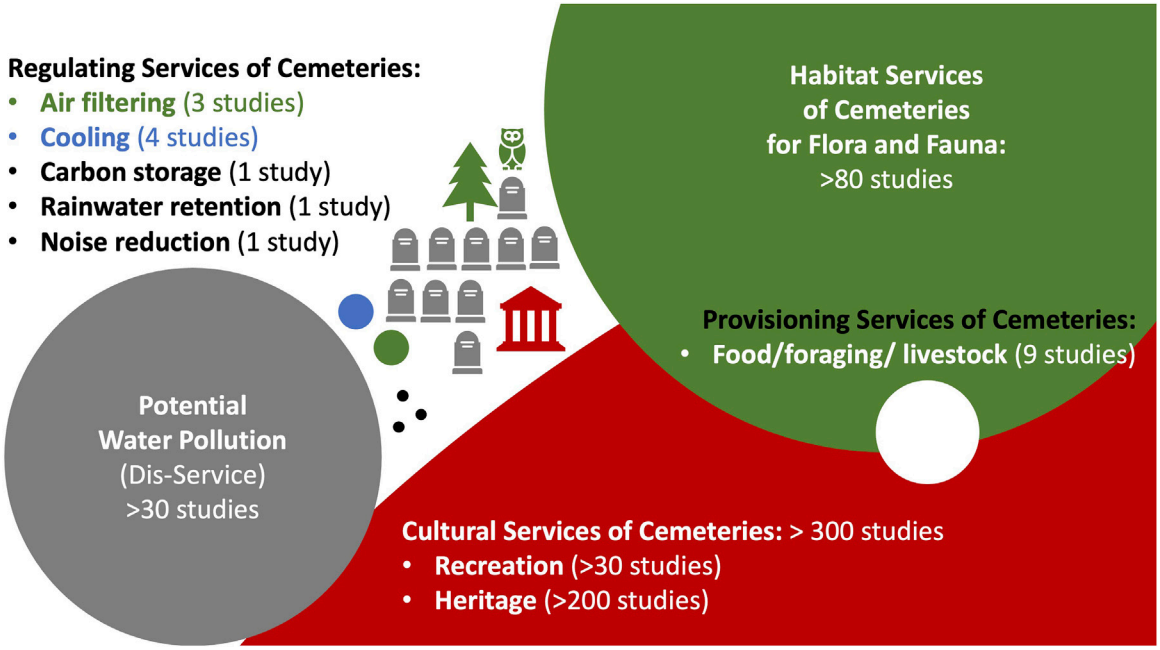

FIGURE 3
Overview of studies on ecosystem services provided by urban cemeteries. The diameter of each circle is related to the number of studies identified per (dis) service.

2013; Shackleton et al., 2017) as dogs and their contamination, a major concern of foragers, are not permitted (Landor-Yamagata et al., 2018; Brandner and Schunko 2022). Overexploitation of these resources can, however, also threaten vegetation and wildlife, as in the case of the use of orchid tubers from Turkish cemeteries for culinary purposes (Löki et al., 2019).

The original churchyards were mostly simple meadows around churches where cattle grazed, laundry dried and markets were held. The dealing with death was a task done by the neighbors of the deceased with a great variety of rituals. In the Age of Enlightenment, it became increasingly regulated, standardised and officialised (Spannhoff, 2021). In the more recent past, there is considerable evidence of fodder growing for livestock, beekeeping, plant and tree nurseries and vegetable gardens at cemeteries, at least for food supply for the pastors and grave diggers, and also in times of wars and crisis for a wider public (Jenz, 1977; Happe, 1989). The large meadows of the Parkfriedhof Berlin-Neukölln were regularly harvested by a local farmer and used for winter fodder until the 1970s; a win-win situation for the farmer and the cemetery administration (Jenz, 1977). Some of the meadows at Heidefriedhof Gatow in Berlin-Spandau have been used for extensive livestocking (Morgenroth, 2009). As public urban parks, cemeteries in the 19th century produced their own plant and tree saplings in nurseries or fir greenery for winter grave covering (Morgenroth, 2009), a tradition currently already being tested in some of the cemeteries in Berlin. Several examples of urban gardening in cemeteries (Cemetery Matzleinsdorf in Vienna, Austria; St. Elisabeth-Friedhof II in Berlin-Gesundbrunnen; Central Cemetery in Braunschweig, Germany) or in former cemeteries (St. Jacobi Berlin-Neukölln) have been reported, some involving controversy.

Discussion

White spots on the map of ecosystem services provided by cemeteries

The cultural ecosystem services of cemeteries are widely recognized and studied in literature of social and historical sciences (Figure 3; Pinto et al., 2022). Nevertheless, we identified knowledge gaps and revealed that the interplay of the cultural, social, religious and natural aspects has rarely been discussed in a holistic manner crossing disciplines and diverse stakeholder perspectives. Interdisciplinary studies on cemeteries that include both the human sciences and the natural sciences are scarce. In terms of historical plant use, we have identified a gap in research on grave plantings, which presumably also follow planting fashions, but which may also have ecological consequences, as demonstrated by the frequent introduction of neophytes as ornamentals, and where more naturalistic

planting and maintenance would also be more compatible with conservation goals.

Habitat services and the role as hotspot of phytodiversity within the urban matrix have been studied well for Central European cemeteries (Figure 3). However, a more holistic assessment of biodiversity with multi-taxon approaches beyond the often-studied plants and birds are needed to do a step forward on understanding of ecological trap or source processes of such refugia within the urban matrix. Further, there remain many questions about positive (or negative) effects of linkages with adjacent uses. For example, better linkages with other habitats may be beneficial to certain species, and cemeteries may act as stepping stones to connect biotopes while these openings threaten the refuge function for other species or might provide invasion windows e.g., from ornamentals used in grave plantings to other habitats. Addressing these knowledge gaps is necessary to integrate cemeteries more meaningfully into urban green networks and also to balance conservation, historic preservation, management, and recreational uses as gardens of life.

As regulating services are poorly studied (Figure 3), our knowledge is mostly based on transfers from results from other green structures such as parks or urban forests to cemeteries. However, the number of studies on the disservice of potential water pollution by cemeteries demonstrate that these extrapolations might be problematic at least for soil related ecosystem services. As an example, the role of these areas for rainwater infiltration is regularly excluded in studies and rainwater management of cemeteries often looks for closed loops between rainwater harvest from neighboring buildings, and collection in cisterns for use for watering plants on graves (Afla and Reza, 2012; Benden et al., 2017). In general, there is a strong dominance of studies on regulating services provided by public parks (Brzoska and Spage 2020; Pinto et al., 2022). The reason for this is certainly the accessibility of these public spaces to citizens and their dominant role in public discourses such as "parks-as-social-healers" or about the "democratic nature of parks" (Mullenbach, 2022). In addition, large structures such as urban parks are thought to have a greater impact (but see Cheng et al., 2015). However, cemeteries can be the same size as parks (Figure 2A) without becoming a prominent research subject. This shows their special role as untouchable places and is not surprising in a society that hardly deals with dying and transience. There were certainly advantages to not being in the public discourse, as natural and cultural treasures were thus kept hidden. However, these spaces are therefore also particularly vulnerable and have few defense mechanisms against claims that come from the outside. Studies on provisioning services are rare for cemeteries (Figure 3) as well as for other green structures (Pinto et al., 2022). At the very least, urban food production in public spaces became a research topic for urban green spaces in the wake of the revival of the Edible City movement in the last decade, which has also reached cemeteries (Säumel et al., 2019; Sartison and Artmann 2020; Russo and Escobedo 2022).

Cemeteries in transformation

Cemeteries appear, experience crowded times, are abandoned and sometimes disappear. Thus, Central European cemeteries also follow a type of ontogenesis as proposed for Australian cemeteries by Davies and Bennett (2016). Abandoned cemeteries regularly develop into (wild) urban forests (Cloke and Jones 2004; Nowinska et al., 2020; Quinton et al., 2020). From the biodiversity conservation perspective, cemeteries should be preserved as refugia for flora and fauna (Löki et al., 2019), and sustained with public funds, even though their owners are private organisations (Bauer et al., 2015). Care taking interventions are needed to maintain the habitat qualities that sustain the high conservation values, especially for target species (Verschuuren et al., 2010; Kowarik et al., 2016; Löki et al., 2019), but there are also for safety concerns if people explore the area on defined paths.

In dense cities with high land use pressures and low access to public green, cemeteries are increasingly used by local residents, this underlines the need for strategies for shared habitats for people and nature (Evensen et al., 2017; Swenson and Skar 2019; Straka et al., 2022). The first steps of transformations have taken place in some cemeteries, with moves towards areas of nature conservation and urban wilderness or public green with sport facilities, playgrounds or urban gardening and environmental education. However, proper evaluation of these processes is lacking (Hornbogen 2014). There are also examples of conversion to construction sites for schools or residential buildings, though cemetery associations prefer the use of cemetery land as burial grounds through adapting to the new forms of burial and mourning (Morgenroth, 2009). Fortunately, long statutory periods of rest and piety after the last burial protects cemetery land from rapid conversion, although the pressure to assign alternative uses is enormous in growing cities with a lack of affordable housing or green space in dense neighborhoods.

Ownership plays a crucial role in decision making (Basmajian and Coutts 2010). Economization of burials was intensified in the 19th century (Bähr and Hajduck 2015). The burial sector in many former socialist countries has been privatized in recent decades, and occupancy rate in the public cemeteries has decreased from over 90 to around 60 percent (Folikova Palanova and Juraka 2018; Rusu 2020). As cemeteries are predominantly financed by burial fees and the costs of communal cemeteries are partially covered by public budget, there is growing economic pressure on cemetery administrations (Morgenroth 2009; Hornbogen 2014). The changing demands for burial ground have led to decreasing income from fees, while the maintenance costs remain (Venne et al., 2016). In Germany,

there is a tendency to 'sponsor' historically significant graves with new burials on valuable, listed older graves, and to preserve and repair high-quality surviving grave structures with the fees (Berlin 2010). Cemetery administrations provide citizen services with goals other than those of the private funeral sector, which seek profit in the multi-billion-euro death-care business (Venne et al., 2016). As in other sectors, the profit is privatized but the costs are public, although it should be highlighted that the funeral sector is still dominated by locally rooted and often family-based enterprises. Thus, a re-municipalization of some more profitable parts of the funeral business or the support of cemetery care services by the private sector has potential as a strategy to balance the costs of cemetery maintenance as a part of urban commons. The cost situation is particularly critical for cemetery operators of formerly large religious communities such as the two Christian denominations in Central Europe. Here, too, burial numbers are declining. Unlike municipal cemeteries, they receive no public support for the costly management and maintenance of these publicly accessible green spaces. On the one hand, this can lead to a very critical state of maintenance in these cemeteries, which should be avoided by supporting the owners in a nature- and monument-friendly maintenance. For economic reasons, such operators then also decide to exploit the area of former cemeteries as building land. This regularly leads to very controversial discussions about these types of transformations and illustrates the emotional dimension of the space of the cemetery.

Cemeteries remind us not only within our lifetime of previous generations of our grandparents or parents but also that we are finite and that nothing is as certain as the end of our lives. Visitors must ask themselves what remains of them. Cemeteries thus touch us directly and are sensitive spaces of farewell, inheritance and reflection 'on the meaning of our lives'. Consequently, the transformation of cemeteries is something that touches each of us personally, and is a matter that brings together, or should bring together different needs, interest groups and institutions. Religious, economic, cultural and ecological questions have to be asked, and a consensual way of dealing with different perspectives has to be found. This requires a debate that involves as many affected groups as possible. Cemeteries are therefore also special places of gathering in a highly fragmented urban society, with a special cultural role and in terms of reverence for human life and death. It is essential to take this significance into account in the process of redesign, which is a lengthy undertaking and requires compromise on all sides. Although one of the main arguments against such redesign is the reference to the apparent immutability of these places, historical analysis shows that cemeteries have long been used for a variety of purposes besides their main purpose (burying and commemorating the deceased), and have undergone numerous changes throughout history. These concerned changes for religious, social, economic or political reasons. These changes in the past not infrequently emanated from the institutions (churches or municipalities) that were in charge of the cemeteries. Thus, above all, if reasons of reverence and (religious) dignity that could be cited against change are respectfully addressed, and the various social groups are involved in the process of redesign, it may be possible to give cemeteries a different meaning and to accommodate new interests without violating cultural and social norms.

Knowledge gaps and management challenges

As conservation biology recently started to use the multi-taxon approach to analyze habitat functions in cemetery (Kowarik et al., 2016; Löki et al., 2019), the analysis of functionalities and benefits of cemeteries needs a holistic and transdisciplinary approach across stakeholder, sectors and disciplines. Urban multi-use corridors combining burial plots and greenspaces have been proposed to protect memories of the past (Scalenghe and Pantani 2020). The rising interest in understanding the mechanisms and processes related to cemeteries within the urban matrix will help to fill knowledge gaps and to develop effective strategies to deal with the treasure that are urban cemeteries by combining the diverse perspectives (e.g., Nash 2018; Grabalov and Nordh, 2022). To date, cemetery transformation has often been in reaction to urgent pressures, and not involved informed decision making. Step by step processes, monitoring success and failure, is key to addressing concerns and satisfying the expectations of all actors. Though the social integration of the cemetery in the neighborhood can be lost over time (Harvey 2006), enhanced access and multifuntionality can reintegrate them (e.g., Swensen et al., 2016). However, multifunctionality is related to competing demands and conflicts (Klingemann, 2022), so co-creation could be key to keeping the neighborhood connected with the cemeteries, envisioning and implementing its future with all actors and avoiding that actors are unheard due to power asymmetries. Incorporating and articulating cemeteries' intangible values, including spiritual and religious ones to politics and decision takers (McClymont 2018; Grabalov and Nordh, 2022) while maintaining cemeteries as calm, quiet, and meditative spaces (Skår et al., 2018) is a challenge.

There is no one solution fits all and, as city-wide planning approaches are limited to addressing the singularity of cemeteries and different zones within cemeteries, there is an urgent need to move from city-level plans to cemetery-specific strategic policy documents (e.g., Grabalov and Nordh, 2022). Since unplanned but deliberate planting of graves leads to arbitrary distribution of woody plants, the preservation of the specific characteristics of abandoned cemeteries is a challenge for garden heritage conservation. There are ongoing discussions between

disciplines and actors about what is worth preserving, which mixture of woody plants should remain in order to maintain individual character (Butenschön and Beck 2011). Conflicts between people mourning and other users indicate that multifunctionality also has limits. Balancing between wilderness and being well-kept (Skår et al., 2018; Kowarik et al., 2016), between nature and heritage protection, between isolation and integration into the urban fabric or between different use options and actor groups, requires a higher level of maintenance than other types of urban green space (Skår et al., 2018). Expanding the multifunctionality of cemeteries requires zoning for different purposes and community learning processes to deal with tensions, culture and tolerance (Grabalov and Nordh, 2022).

Conclusion

Beyond the common classification into neighborhood, park, and forest cemeteries, the reality of cemeteries is very diverse with numerous hidden places, small arenas, habitats, and niches between culture and nature, sculptural and wilderness (Figure 1). All those who take a closer look at this diversity of cemeteries realize that for the transformations of cemeteries there can only be individual and no uniform solutions. Cemeteries appear to be stable in one's lifetime, but historical studies provide not only evidence on foundation and expansion of cemeteries but also from declining demands to disappearances or renewals. Neighborhoods with a healthy mix of different generations have many advantages among them avoiding wave-like movements between above-average but also below-average demands for burial places. Long waiting periods protect cemeteries and the relatives of deceased against hasty decisions based on uncertain forecasts, thus allowing reactivation of burial activities after e.g. a period of use as a park. Moreover, cemeteries are very complex entities of the urban matrix with unknown interactions with neighboring uses, have received so far little attention from planning and natural sciences and have remained poorly studied especially regarding regulating or provisioning services. Knowledge on phytodiversity of cemeteries have been collected to a larger extent compared to other organisms, but multitaxon studies are scarce, a fact that cemeteries share with other urban green elements. In contrast, humanities have produced a much richer literature on history, development and socio-cultural functions and thus also gathered a lot of knowledge on so-called "cultural ecosystem services" provided by cemeteries without using the concept of ecosystem services. The results of the present study, in conjunction with further future work, offer the possibility of creating a reference basis for which aspects must also be taken into account in a future cemetery redesign. On the one hand, the transdisciplinary approach of such a process should be mentioned; on the other hand, it can also open up new social solution horizons that reduce potential tensions between actors and interest groups. However, a corresponding discussion in society as a whole about the significance and change of cemeteries, which takes all aspects into account equally, is only just beginning.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

All authors did the research and conceptualized the manuscript. IS wrote the first draft of the manuscript. NK and SB reviewed the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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