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Review Paper

Biodiversity potential of burial places – a review on the flora and fauna of cemeteries and churchyards

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ABSTRACT

During the past centuries human-induced land use changes resulted in a considerable loss of natural habitats worldwide. In transformed landscapes historical burial places such as cemeteries and churchyards can have the potential for biodiversity conservation. In our review we aimed at evaluating the conservation role of these sites and at revealing factors that can threaten their biota. Altogether we evaluated the results of 97 relevant studies from five continents. We found that cemeteries and churchyards have a considerable conservation role, as even in heavily transformed landscapes they often act as refuges for the populations of rare and endangered species; altogether 140 protected taxa were listed in the reviewed studies. We revealed that the high biodiversity of burial places is supported by their long-term existence and their undisturbed status. However, in parallel with changes in the social attitude the management of these natural refuges has also been altered worldwide. We identified the major threats for the flora and fauna to be altered burial habits decreasing the area of grasslands, intensified management of the cemeteries by frequent mowing and logging, the spontaneous and human-induced introduction of invasive species and the overexploitation of natural resources present in cemeteries. As conservation and spirituality is tightly interwoven in cemeteries, the preservation of these refuges can be achieved by the reconstruction of their sacred spirituality, by raising the attention of local populations for the natural values of these areas and also by specific, focused management providing proper habitats for the natural flora and fauna.

1. Introduction

During the last couple of centuries land use has changed considerably. Intensification of agricultural practices, deforestation and urbanisation has led to a dramatic decrease of natural vegetation worldwide. This decrease has been especially pronounced in the densely populated European continent, where the landscape has been cultivated since the Neolithic with ever increasing intensities (Barbujani and Bertorelle, 2001). Loss of natural habitats has been most pronounced in areas where soil conditions are favourable for agricultural crops. In such heavily transformed landscapes, small, relatively undisturbed habitat patches have a particular conservation importance as they act as refuges for biodiversity (Saunders et al., 1991). Such habitat patches are represented for example by deforestation boundaries (Schonewald-Cox, 1988), roadside verges (Cousins,

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2006; Fekete et al., 2017), field margins (Vickery et al., 2009) and abandoned mines (Shefferson et al., 2008) as well as ancient earthworks (Suder, 2011), burial mounds (Deák et al., 2016, 2018; Valkó et al., 2018), sacred groves and forests (Bhagwat and Rutte, 2006; Brandt et al., 2013), cemeteries and graveyards (Barrett and Barrett, 2001).

Sacred natural sites with high biodiversity can be found all over the world; sacred groves, sacred forests and church forests are the most widespread among them. Nonetheless, sacred hills, caves and islands and water bodies connected with religious beliefs like sacred rivers, lagoons and springs are also common on several continents (Verschuuren et al., 2010), and they also serve as biodiversity refuges. Conventional cemeteries are the most common, appearing in significant numbers worldwide, and they usually are of large spatial extent (Rugg, 2000). However, more special burial practices and rituals also exist to date (e.g. the Tibetan sky burial ceremony, where vultures consume the bodies; Martin, 1996). The number and type of burial places in a given area is mainly dependent on the religion and the size of the local human population. For example, in the steppe zone of Eurasia and in the contact areas of the forest-steppe zone, burial mounds (kurgans) often represent the last guardians of steppe vegetation in eastern Europe, where intensive landscaping and agriculture dominates, eliminating most of the natural steppe vegetation (Cremene et al., 2005; Moysiyenko et al., 2014; Sudnik-Wójcikowska and Moysiyenko, 2011). According to Deák et al. (2016), kurgans still provide a variety of micro-habitats of different environmental conditions, which allows for the presence also of sensitive and rare organisms.

The role of these sacred burial places in biodiversity conservation is further emphasised by the fact that most of them were established in ancient times, when the extension of natural habitats was continuous. Little is known, however, about the influence of burial practices, management of cemeteries, religious identity and cultural background of these sacred places on their role in biodiversity conservation. Therefore, here we aim to study these questions by means of reviewing the existing literature of burial places.

The dead can be buried in different ways, mostly depending on the local cultural heritage. In the modern Christian culture, burying the dead was only allowed on the lands surrounding the church, and this was the only burial method used by Christians for centuries. As such, there are historic differences between graveyards and cemeteries. Graveyards were considered to be part of the churchyard ("*churchyards are often small tracts of burial land owned by and located close to the Church and used over centuries*'; Rugg, 2000), while cemeteries are '*burial grounds, especially a large landscaped park or ground laid out expressly for the deposition or interment of the dead, not being a churchyard attached to a place of worship"* (Rugg, 2000). According to Curl (1999), … cemeteries *"often larger in scale and predominantly owned by secular authorities - have been in common use only since the* 19th *century*". Cemeteries are generally located close to, but not necessarily within the settlements, depending on the local cultural traditions; however, Muslim cemeteries are often located quite far from the settlements (Sagona, 2006).

It recently became recognised that sacred burial places are key in conserving natural vegetation in their area (Barrett and Barrett, 2001). Cemeteries often encompass large habitat patches, which are characterised by low intensity land use and generally remain unaffected by most land use practices in the surrounding area. Cemeteries therefore are "islands" of natural vegetation in close proximity of urban areas, often harbouring rare and endangered plant species. The key importance of cemeteries in nature conservation is therefore nowadays unquestionable (Bhagwat, 2009).

Numerous countries have recognised the nature conservation and cultural importance of cemeteries and churchyards in recent decades (Laske, 1994; Dudley et al., 2010). Most burial sites were created in times when the landscape was extensively cultivated, and they were traditionally respected for piety reasons. Even today these burial sites are largely exempt from forest and agricultural utilisation. The natural values of burial places have been ignored for centuries, but as recently revealed, cemeteries and churchyards can be guardians of intact habitat patches in the landscape, and they also have a significant, underestimated role in conserving natural values with special needs (e.g. Trewhella et al., 2005; Löki et al., 2015). Whereas several studies have been carried out to reveal the cultural and archaeological values of burial places, their natural values are still understudied despite a recent increase in research interest (Verschuuren et al., 2010). Based on topical studies (Molnár V. et al. 2017a, Verschuuren et al., 2010), significant differences in the conservation role of cemeteries and churchyards can be found depending on location, land use, biogeography and cultural traditions; therefore, thematic examinations of cemeteries in different regions would be timely in order to reveal which cemeteries have the most prominent role in conserving biodiversity. In this paper we aimed to (i) review the most widely studied taxa that have been in the research focus so far, (ii) identify regions in which cemeteries have an important conservation role, (iii) reveal knowledge gaps regarding the first two study questions, (iv) review the main threats for the wildlife of burial places and (v) evaluate the most appropriate management methods for conserving the biodiversity of burial sites based on the results of available studies.

2. Materials and methods

We searched for articles on the role of cemeteries and churchyards in biodiversity conservation. Our review therefore focuses exclusively on cemeteries and churchyards with special attention to their conservation values; other sacred sites with similar burial functions (e.g. sacred groves, church forests) are not considered. We performed three literature searches using Google Scholar. First, we used the keywords 'conservation' AND 'cemetery' OR 'graveyard', which returned 55,000 hits (papers published before March 2018). Second, we performed two further searches using the keywords 'cemetery' AND 'conservation' (second search; 15,200 hits) and 'graveyard' AND 'conservation' (third search; 6330 hits), respectively. From each of the three searches, the first 1000 papers were screened by title and abstract (altogether 3000 papers). In total, 97 papers were found to be relevant for our review. After studying the abstracts of studies chosen by their relevant titles, 31 papers were discarded

based on their content. On the other hand, we added another 31 papers on looking through the reference lists of the reviewed studies. Thus we reviewed the results of a total of 97 papers in the present study. In spite of our extended literature search, there might be further information in non-electronic sources or in languages other than English, which we could not include in our review. We used the nomenclature of Plant List for all referred plant, and CABI for all referred animal taxa. We considered an alien species as invasive, if it was consequently referred on this term throughout the reviewed paper.

3. Results and discussion

3.1. Number of available studies and geographic distribution

Studies were from 22 countries in five continents (Fig. 1). Most of the available case studies (excluding reviews) focused on Asia or Europe (63), while other continents were represented by 28 studies. 34 papers (38%) were from Europe, 29 papers (33%) from Asia, 15 studies (17%) from North America, 10 (10%) from Australia and New Zealand, and 3 (2%) from Africa. None of the reviewed papers provided any data from South America (Fig. 1). Nowadays the traditional use of churchyards for burial purposes is mainly a characteristic of Anglo-Saxon regions (UK, US); elsewhere, cemeteries are widespread (Rugg, 2000). According to Rugg (2000), cemeteries are generally 4–6 ha in size, and their area is often expanded; based on our own data, cemeteries in Europe are generally smaller (Electronic appendix Table E3).

In total, 20 papers were about the flora and vegetation of cemeteries and graveyards in the EUCGC, while we found only 11 papers on their fauna. Most cemetery-related research (18) comes from Turkey. Most of the papers concentrate on a bounded region, and totally four papers (Tryjanowski et al., 2017; Molnár V. et al. 2017b; Morelli et al. 2018a; Morelli et al. 2018b) provides a multi-country approach (Electronic appendix, Table E1). In addition, a total of five policy papers were found.

The topic is likely to become even more popular in the future, partly because of the recent popularity of cemeteries' wildlife research (the number of Google Scholar search results for 'graveyard' OR cemetery AND 'conservation' grew continuously between 1970 and 2000), partly because researches on urban environment are globally increasing.

3.2. Role of cemeteries in conserving wildlife and number of (protected) organisms

In the reviewed papers, the authors studied 1–631 cemeteries. While in the late 1980s and early 1990s the attention of researchers was mainly directed to the flora, cemeteries have been known as bird refugia for decades; one of the first papers on this subject was already published in 1915 (Pearson, 1915). Cemeteries are known to be important refuges for lichens (Hawksworth and McManus, 1989), mosses (Fudali, 2001), rare mushrooms (Brown et al., 2006), rare and endangered plant species (Sigiel-Dopierala and Jagodzinski, 2011; Molnár V. et al. 2017b), rare herbs used for ethno-medicinal purposes (Dafni et al., 2006; Hadi et al., 2014), trees that are significantly older than those in the surrounding areas (Gao et al., 2013; Preston, 1972), nesting birds (Kocian et al., 2003; Lussenhop, 1977) bats (Trewhella et al., 2005) and mammals (Čanády and Mošanský, 2017). In the reviewed studies, a total of 140 protected species were found in cemeteries and graveyards. In 16 of these papers, 70 protected plants and 49 protected animals were identified (Electronic appendix, Table E2).

3.3. Flora of cemeteries

Studies on the flora of cemeteries are often strongly biased: Eleven papers provided information on orchids, which can also be considered to be umbrella species in biodiversity researches (Box 1).

Within Europe, the flora of cemeteries has been best studied in Poland. Several descriptive papers discussing the species composition are available from this country: Fudali (2001) studied the bryophyte flora of cemeteries in Wrocław, while Czarna and Piskorz (2005), Sigiel-Dopierala and Jagodzinski (2011), Trzaskowska and Karczmarz (2013) and Czarna (2016) found hundreds of vascular plant species in old cemeteries of Zakopane, the Drawsko Landscape Park area, Lublin and Poznań. Antkowiak and Heine (2005) studied the dendroflora of 47 historic cemeteries in the Koło district, while Sudnik-Wójcikowska and Galera (2005) compared four sites of anthropogenic habitats (the tram-line network, habitats in the area of the Palace of Culture and Science, three botanical gardens and a total of 24 cemeteries) in Warsaw. The latter authors found the largest number of plant species in the three botanical gardens (675), followed by cemeteries (585), the tram-line network (213) and the Palace of Culture and Science, where 111 species were present.

Šilc (2009), who examined the vegetation of a cemetery in Ljubljana (Slovenia), found that disturbances are frequent and intensive and that the vegetation is unique, highly diversified and extremely thermophilous. Kowarik and his co-authors (Kowarik et al. 2011, 2016; Buchholz et al., 2016) made the most thorough evaluation of a single cemetery and found 363 vascular plants, 72 lichens and 26 bryophytes in the largest Jewish cemetery of Berlin, Germany, encompassing 10 protected plant species.

Cemeteries of North America (as well as some countries of Asia) are among the most intensively studied cemeteries in the world. Researchers documented more than 50 years ago that in the central areas of North America, cemeteries can preserve patches of tallgrass prairie remnants (Shelford, 1963). This is especially important because the tallgrass prairie is one of the most endangered grassland habitat types in the world (Wright and Wright, 1948; Anderson, 2006). Could (1941) recorded a total of 23 species characteristic for tallgrass prairie, including rare prairie plants like *Eryngium yuccifolium*, in a cemetery. Phillippe et al. (2010) studied the vascular plants of the Short Pioneer Cemetery Prairie Nature Preserve (Illinois, US) and

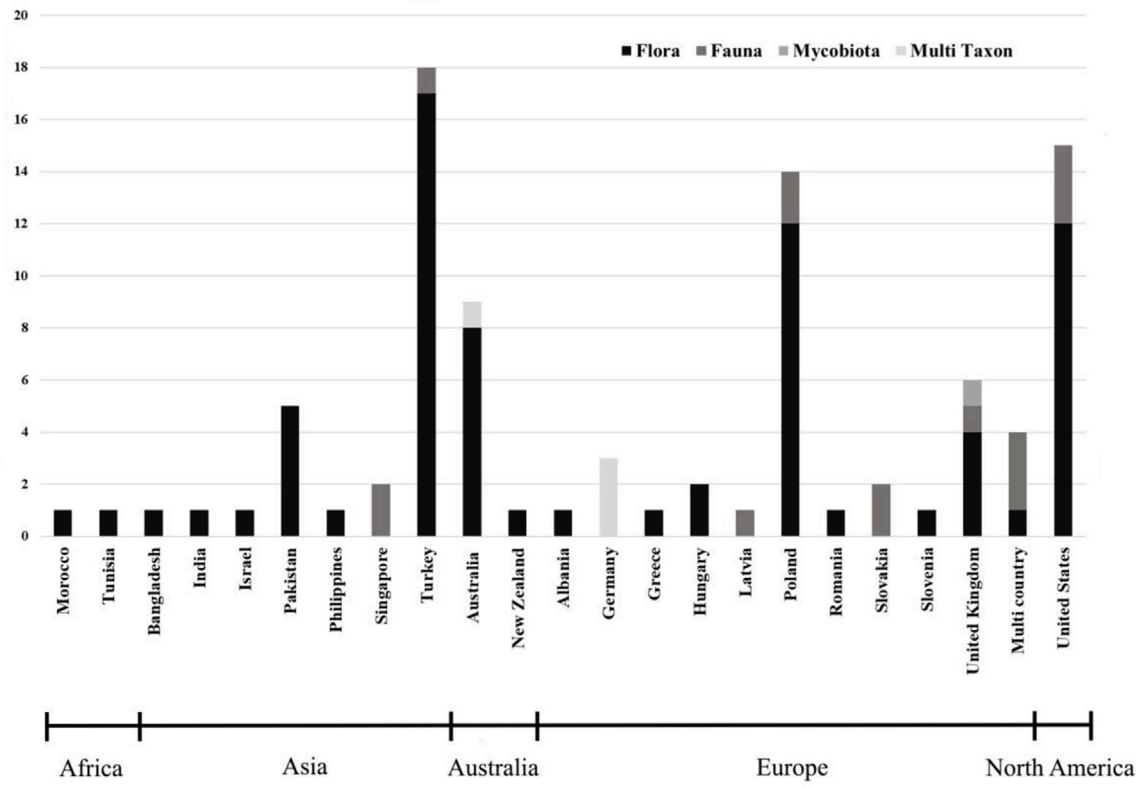

Fig. 1. Number and geographic distribution of reviewed studies.

determined the change of the cemetery area since 1977 based on the work of Harty and Strange (1976). The authors found a total of 137 vascular plant species and noted that at least 15 species had disappeared from the area since 1977. They suggest that one of the possible causes for species decline is the small extension of the area (0.5 ha). Anderson et al. (2011) surveyed 6 cemeteries in Illinois; he noticed that while formerly the tallgrass prairie had covered near 60% of Illinois, only 0.01% of their original stands remained intact. He also considered that the small remnant habitat patches, though unsuitable for large mammals or birds, can still support a high floral diversity (see also Ellis, 2008). Ruch et al. (2014) studied three cemeteries in Indiana, which contained prairie habitat patches. The authors found a total of 184 plant species, of which 75% were native. The authors identified 46 non-native species, of which 29 belonged to the family of sedges (*Cyperaceae*).

Similar studies are reported from Australia: According to Prober and Thiele (1995), numerous native species are present in Australian cemeteries, such as the rare *Eucalyptus albens.* Morgan (1999) considered cemeteries to be the most important habitats of a rare plant, *Rutidosis leptorhynchoides* (Asteraceae). Although sometimes the last viable populations of sensitive organisms are present in cemeteries, the species composition can significantly differ from natural habitats. Loneragan (1975), who studied the ecology of a West Australian graveyard (Gingin), analysed how special circumstances of cemeteries affect the floral composition. The author suggests that the species compositions of cemetery habitats differ from the natural grasslands, as many disturbance-tolerant species are present due to the permanent establishment of graves. Prober and Thiele (1995) also stated that in cemeteries where *Eucalyptus albens* occur, the plant species numbers decrease with increasing grazing intensity.

In the Far and Middle East, cemeteries harbour numerous plant species with significant medicinal or ethnobotanical value to the locals (Shah et al., 2016; Hadi et al., 2014; Dafni et al., 2006). The most representative study was conducted by Rahman et al. (2008), who studied herbs of three cemeteries in Rajshahi, Bangladesh. They identified a total of 49 plant species growing in cemeteries that are regularly used by the local people to treat various diseases. The authors also highlight the presence of six species that are extremely rare in the surrounding areas. Although the age of cemeteries was not evaluated in these studies, the role of ancient cemeteries in conserving biodiversity is presumably high: in a recent study, Kamran et al. (2019) found that older graveyards with higher soil nutrient, calcium and magnesium content has higher number of indicator plant species, and have higher plant diversity in Bannu district, Pakistan. In Turkey, Kırmacı and Ağcagil (2009) studied the moss flora of urban territories and found 21 of the 123 bryophyte species identified in their study in two cemeteries. Uslu (2010) drew attention to the importance of an abandoned cemetery in Ankara for its value as a green area within a highly urbanised region. Yılmaz et al. (2018) also stressed the unique role of cemeteries in biodiversity conservation within urban habitats. The authors found 280 vascular plants in a cemetery within Istanbul. This figure is especially impressive given that

Box 1
Presence of orchids in cemeteries

During the last decades it has become common knowledge that several orchids are able to populate anthropogenically influenced, partially confined habitats such as mines (Jurkiewicz et al., 2001; Shefferson et al., 2008), poplar plantations (Adamowski and Conti, 1991), road verges (Rai et al., 2010) and cemeteries. More than forty years ago, Tony Price reported several terrestrial orchid genera (*Diuris, Microtis* and *Thelymitra*) from the cemetery of Auburn (Australia) at 1979 (Hewitt, 2013). Plumwood (2007) reported the orchids *Diuris aurea, Diuris sulphurea* and *Diuris punctata* from the cemetery of Major's Creek (Australia). Hoey and Lunt (2003) reported the rare orchid *Prasophyllum correctum* from several cemeteries in Australia. In Europe, Kowarik et al. (2016) reported the broad-leaved helleborine (*Epipactis helleborine*) in their study about the wildlife of the largest Jewish cemetery in Berlin. In Turkey, at least 8 studies and a book reported some orchid species from different cemeteries (Arslan et al., 2012; Kreutz and Peter, 2007; Kreutz 2010, 2013; Kreutz and Çolak, 2009; Kreutz and Krüger, 2014; Baumgartner et al., 2016; Löki et al., 2015, 2019). In a comprehensive field survey of Turkish cemeteries, Löki et al. (2015) found orchids in 208 out of 300 surveyed cemeteries, pointing out that almost half of the Turkish orchid flora was also detected in cemeteries. In the cemeteries of the Carpathian Basin, 26 orchid species were found (Molnár V. et al., unpublished). All in all, we can state with confidence that orchids regularly appear in cemeteries throughout Europe (Löki et al., unpublished). Although the topic requires further studies, field observations indicate that beyond geographic and climatic factors, cultural characteristics can also be important drivers of the orchid species composition in cemeteries. Molnár. et al. (2017a) compared the orchid flora of Muslim, Christian and mixed religion cemeteries in Albania and found 29 orchid species (35% of the Albanian orchid flora) in the studied 166 cemeteries. They also found that Muslim cemeteries harboured more orchid species and individuals (mean number of species: 1.57; $n = 85$) than Christian cemeteries (0.67; $n = 50$) or mixed religion cemeteries (1.54; $n = 21$). The difference is probably due to different management methods based on religious traditions, as Muslim cemeteries are usually less intensively managed (Champion et al., 1965). Examples of western European countries suggest that the habitat management is probably more intensive in economically well-developed countries (Plumwood, 2007).

the area of the studied cemetery represents only 0.1% of Istanbul's area, while the list of native plant species detected here encompasses 5.5% of its flora.

Contrary to plants, very little is known about the mycobiota of cemeteries and churchyards. Fortey (2000) indicated the presence of 14 rare mushroom species in the churchyards of Oxfordshire. His article suggests that burial places might represent refuges not only for plants, but also for other life forms, and therefore deserve further scientific and conservation attention.

3.4. Fauna of cemeteries

Numerous animal species can be encountered at various burial places, including both vertebrates and invertebrates. Nonetheless, little is known about the importance of these habitat patches for animals, and the available geographical and historic information is very limited. Within Asia, a study highlighted the presence of 87 beetle species belonging to 13 orders in a small cemetery (3 ha) in Turkey, including several species that are rare or endangered in Europe (Atay et al., 2012). The Orthoptera fauna appears to be similarly rich in cemeteries. Tan (2012) and Tan et al. (2013) examined this group in the Bidadari and Bukit Brown cemeteries and compared it to the Orthoptera fauna of the Central Catchment Nature Conservation Area in Singapore. They found the cemeteries to host a more diverse Orthoptera fauna than the surrounding natural habitats. Örstan and Kösemen (2009) found ten snail species in an old Jewish cemetery in Istanbul (Turkey), which is considered to be a high diversity of snails in such a small area. The authors found that among the detected species, *Helix pomacella* was the rarest in urban environments. This species reportedly also occurred in an ancient Greek cemetery in Istanbul (Örstan, 2004). The authors emphasise the importance of cemeteries for snails, a group that has been significantly compromised by habitat loss recently.

The bird life of the last green areas of Manila, including two military cemeteries, was studied by Vallejo et al. (2009). The authors report a total of 70 bird species in eight sampling sites, of which 30 were present in the two sampled cemeteries. According to the authors, it is important to note that even though hunting has a long history in the Philippines, such activity is culturally unacceptable in cemeteries, which adds to their importance in providing protection for wildlife. In North America, 22 bird species were reported from 10 cemeteries in Chicago (Lussenhop, 1977). Although the vegetation did not differ significantly between these cemeteries and their surrounding areas, the number of detected bird species was higher in the cemeteries than outside, presumably because the neighbouring habitats around the cemeteries were, based on the authors' observations, patchy on a more local scale (<25 ha). In cemeteries where the number of nesting sites appeared to be limited or inappropriate, the bird species nested in adjacent areas, but regularly visited the cemeteries for feeding. Recently, Bovyn et al. (2019) compared the natural and excavated cavities of trees between urban parks and cemeteries in Illinois, USA. These

habitats have similarities in lawn and tree maintenance but have differences in tree characteristics due to different management practices. They found that cemeteries maintain 3.4 times as many woodpecker-excavated cavities then urban parks. Trees in cemeteries tended to be larger and more decayed and have more excavated cavities in cemeteries than those in parks, therefore cemeteries have the potential to be refuges for primary and secondary cavity nesters and maintain more diverse bird population.

In Europe, Kocian et al. (2003) studied nesting birds in three cemeteries of Bratislava (Slovakia) for a period of three years. A total of 33 nesting bird species were found, of which 9 were regularly breeding in the studied cemeteries. The latter study also emphasises that the position of the cemetery within the settlement, its age and its area as well as the structure and age of its vegetation all influence the prevalence of nesting birds. With increasing fragmentation of the habitats within the cemetery, the number of nesting bird species clearly increased. Most birds nested in the smallest, most isolated cemeteries due to the heterogeneity of their vegetation (Kocian et al., 2003). The authors also quote a number of studies listing bird species previously not known to nest in Slovakian cemeteries and urban parks (based on the works of Biaduń (1994) and Luniak (1981)). The role of churchyards was also investigated in conserving birds in southern Poland: 68 bird species were found around a total of 101 churches (Skórka et al., 2018).

One of the most comprehensive studies on cemeteries was conducted on one of the largest Jewish cemeteries of Europe, the 39.2 ha cemetery in Weiβensee, Berlin, where the wildlife was studied for several years (Kowarik et al. 2011, 2016; Buchholz et al., 2016). A total of 34 species of birds, 5 bats, 39 ground beetles, 5 harvestmen and 64 other spider species were detected here, including 3 arthropod, 9 bird, and 5 bat species protected by law. The authors of the study, which was the first attempt to overview the complete wildlife of an urban burial ground, encourage other researchers to carry out more similar, comprehensive surveys.

4. Factors endangering the wildlife of cemeteries

4.1. Ornamental plants

Herbaceous ornamental plants are widely planted in cemeteries. Evergreen species (e.g. cypress (*Cupressus sempervirens*) and box (*Buxus* spp.)) are cultivated in cemeteries in many cultures as they symbolise the non-terrestrial inheritance (Sabo et al. 2010; Rebancos and Buot Jr. 2007). In contrast, however, cemeteries of Tunisia completely lack ornamental plants (Brandes, 2011). Furthermore, Palacz (1996) reports that the tradition of planting ornamental plants is completely absent from the Jewish culture and rituals in Poland. The fact that the Jewish culture mostly lacks ornamental plants in cemeteries is also supported by the study of Czarna and Nowinska (2010), who found no ornamental plants in four surveyed Jewish cemeteries.

Most ornamental plants are not necessarily invasive, and most of them can not alter the dominant vegetation, but sometimes in certain regions they transform the habitat structure. Alien woody species, for example, often dominate the landscape of the cemetery for decades. We suggest that lack of ornamental plants can result in a more natural and diverse vegetation in cemeteries, and given that ornamental plants are often cultivated in certain religions, and their percentage of the cemetery's flora is sometimes high, the potential of plant invasions is also a high risk in these habitat patches. In these conditions, many sensitive native species are unable to compete with successful non-native plants (McBarron et al., 1988; Rutkovska et al., 2011).

4.2. Invasive species

Numerous researches focusing on the alien flora of urban environments indicate that invasive plants are usually changing the structure of habitats and represent strong competitors for both common and rare native species (Alpert et al., 2000). The proportion of alien species is exceptionally high in some studied sites: 70% of 1166 species found in 61 gardens in the United Kingdom (Smith et al., 2006), ~75% of Trabzon's (Turkey) urban flora (Acar et al., 2007) and 77% of the 1834 plant species detected in 174 urban areas of the Czech Republic (Pergl et al., 2016). Cemeteries found to be the source of alien moss invasion in New Zealand (Essl et al., 2014); therefore, it is highly presumable that in urban environments the potential for plants to become invasive and spread is higher than in any other environment.

The floristic composition of 17 cemeteries in Campbelltown, South West Sydney, Australia, included only 193 native plant species from a total of 505 species detected (McBarron et al., 1988). A similar proportion of alien species was observed in the case of vascular plant species in four cemeteries in the countryside of New South Wales, Australia (Semple et al., 2009). These studies conclude that cemeteries with moderate habitat disturbance might better conserve the original vegetation, which might also at least partially explain the low proportion of alien species. Regularly mown cemeteries, on the other hand, were much more homogeneous and harboured more alien species than those that were rarely mown or not mown at all (McBarron et al., 1988). Prober and Thiele (1995) studied the last remnants of the rare *Eucalyptus albens* in Australian cemeteries. They found that after removing the eucalyptus groves, the number of alien species increased in these cemeteries. Similar trends can be observed in Europe: The flora of two cemeteries in Thessaloniki, Greece, encompassed 17 and 24 alien species, respectively, from a total of 62 species detected at the two surveyed sites (Krigas and Kokkini, 2004). Trzaskowska and Karczmarz (2013) found alien species (*Solidago canadensis*, *Fallopia japonica*, *Erigeron annuus*, *Erigeron canadensis*) in 4 out of 7 evaluated cemeteries of Lublin (Poland). A total of 49 invasive plants were observed in 10 cemeteries in Daugavpils (Latvia), with *Spiraea*

chamaedryfolia and *Syringa vulgaris* present in all surveyed cemeteries (Rutkovska et al., 2011). According to the latter study, there is a strong positive correlation between the number of invasive taxa and the area of the cemetery, while the age and religious affiliation of the cemeteries had no effect on the number of species. The authors suggest that invasive plants occupy new niches and displace the local plant species. Although the articles reviewed by us did not provide detailed coverage data of the invasive plants, we conclude that adventive invasive plants are able to transform the cemeteries' landscape in certain cases, and endanger the native flora in the cemeteries of Central Europe. The patterns reported by the reviewed articles suggest that invasion of alien plant species might pose a considerable threat for the habitats preserved by the cemeteries by transforming the cemeteries' landscape in certain cases, and endanger their native flora.

Until today, no thematic surveys for invasive animal species has been conducted in cemeteries. However, some species were occasionally observed from different regions of the world, including four alien snails from Riga, Latvia (Šteffek et al., 2008).

4.3. Intensified management of cemeteries

New, intensified management methods of urban environments have recently become favoured in western societies, which are mostly unfavourable for the natural habitat patches of cemeteries. Ignatieva et al. (2015) reports about the frequent lawn mowing in urban communities of the Western world, which has become one of the main indicators of a well looked-after urban green area. North American communities also favour cemeteries with extremely low and often mowed grass, and they consider the last remaining tallgrass prairie patches '*untreated*' and '*neglected*' (Moorehouse and Hassen, 2004). Hamilton (2008) even made explicit suggestions about cemetery management in Charleston (United States), recommending e.g. the removal of trees that are known to grow large '*before they begin to cause problems*'.

Burial traditions have also changed in the past decades: Stowe et al. (2001) reminds us that in former times only natural materials were used in funerals and cremations, whereas today cemeteries use various artificial objects containing heavy metals, varnishes, sealants, preservatives and toxins, which all contaminate the environment. Exact consequences of using high amounts of specific burial chemicals in cemeteries are largely unknown, but their negative effect on wildlife is highly presumable. In order to moderate the emission of special chemicals used in cemeteries, for instance, it was suggested to use peat for horticulture in cemeteries instead of artificial fertilisers and to implement 'green' funerals (burials free of chemicals and other modern funeral supplies), which would result in a much lower ecological footprint. Holden and McDonald-Madden (2017) also vote on green funerals with a low ecological footprint after reviewing the available literature on the natural values of cemeteries.

4.4. Fading taboos, religious beliefs and ecological knowledge

Taboos, customs, superstitions and other cultural heritages often used to protect the environment of burial places in many countries. The afterlife and the corresponding rituals were associated with a respectful (and perhaps partly fearful) behaviour in the customs of the human kind for thousands of years. Faith has a significant defending role of sacred places and of religious objects and therefore is directly linked to landscapes. However, religious taboos and rituals associated with cemeteries have begun to disappear in many places around the world (Haught, 2010). Moreover, the once commonplace ecological knowledge is also fading in both urban and rural communities worldwide, with broad 'progressive' developments taking over instead (Verschuuren et al., 2010).

Sustaining ecological knowledge in the local population can lead to the successful conservation of various organisms in the long run, as plant species that people know and use in different ways will also be treated with special attention by them. For instance, researchers found the rare orchid *Orchis punctulata* in the cemetery of Kadılar by relying on the ecological knowledge of locals from Antalya (Turkey) (Molnár V. et al. 2017c). This orchid species is, among others, traditionally used for culinary purposes ('*salep*', a sweet delight used in a few countries in Europe and Asia Minor, cf. below in "Other threatening factors"). In this case, even a rare orchid could maintain sustainable populations despite the occasional collection of tubers in Turkish cemeteries (Molnár V. et al. 2017d). On the other hand, the ecological knowledge of Turkish *salep* collectors can help botanists and conservationists to find new sites of rare, endangered orchid populations.

4.5. Other threatening factors

It was assumed that some of the distinctive elements of vegetation and wildlife could survive in undisturbed cemeteries because regular collecting activity is less intense in these places due to piety reasons. Contrary to this general assumption, orchids found in cemeteries of Turkey are sometimes harvested and used for culinary purposes. Turkey is particularly problematic for the intense harvesting of tubers used for the production of traditional Turkish ice cream ('*salepi dondurma*') and a hot beverage ('*salep*'). It was estimated that 1 kg of dried *salep* requires approximately 1000–4350 orchid specimens to be harvested and therefore killed. Based on Turkey's estimated annual collection of tubers it is believed that at least 10–20 million (Kasparek and Grimm, 1999) or 30–40 million (Sezik, 2002) orchid specimens are killed annually. A study investigating the *salep* harvesting activity in Turkish cemeteries reported traces of digging in 14 out of 455 surveyed cemeteries (Molnár V. et al. 2017d). This study estimated that 530 individuals belonging to 17 species were collected as *salep* in the

detected sites. Although collecting in cemeteries does occur, its intensity is relatively low. According to these results, we can assume that cemeteries still provide protection from the collection activity because of their special socio-cultural role.

5. Summary and suggestions for further research

5.1. Present studies and knowledge gaps

The literature on the role of cemeteries and churchyards in biodiversity conservation has grown significantly over the last decade. The main findings of these key relevant studies are the following: (1) Studies of the natural values of burial places are largely conducted in industrialised countries and in some other regions of the world that are studied for specific reasons; thus the publications available to date are geographically highly biased. For instance, Hadi et al. (2014) and Shah et al. (2016) made important studies on the indigenous medicinal flora in cemeteries of Pakistan, while Could (1941), Shelford (1963) and Anderson et al. (2011) investigated the last tallgrass prairie remnants found in cemeteries of states with intensive agriculture in the United States. We suggest that in countries with highly transformed landscapes, it is crucial that the attention of researchers turns to the special habitat patches of cemeteries. On the other hand, we believe that in countries with less drastically changed landscapes, the local role and significance of cemeteries has not been assessed yet, probably because of the higher number of natural habitats in these countries. (2) Based on the reviewed papers, researchers of the papers found by using the keywords explained in "Materials and methods" have mainly studied prominent, easily detectable animal and plant species of cemeteries. Although some of these species work well as ecosystem health indicators, cemeteries should be subjects of more comprehensive surveys, covering multiple phyla and examining them on a wider geographic aspect, with respect to the island biogeography of urban environments in further studies. (3) In general, fewer studies have evaluated the fauna and the mycobiota than the flora of cemeteries: This review comprises 66 surveys of the flora and vegetation, but only 11 of the fauna and just one of the mycobiota (Table 1). (4) Most authors of reviewed papers surveyed cemeteries only once, at one time of the year, so that plants that are blooming earlier or later or animals with no activity in certain parts of the year could have remained hidden during these surveys; therefore, thematic researches with a broader time scale could more effectively evaluate the natural values of cemeteries. (5) It remains largely unknown how geographical, environmental and management characteristics of cemeteries affect their biodiversity. Only a few thematic comparative studies (e.g. Dafni et al., 2006; Löki et al., 2015; Molnár V. et al. 2017a, b, d, Morelli et al. 2018a, b), and reviews (e.g. Bhagwat and Rutte, 2006; Deák et al., 2016) have been conducted on this topic. (6) Another important issue for further detailed analyses is how wildlife is capable to adapt to changed circumstances in urban environments. Duncan et al. (2011) tried to answer this question by analysing 11 functional traits of plants. They found that in countries where plant extinction rates are high, short-statured, small-seeded plants are more likely to become locally extinct. According to Molnár V. et al. (2018), the location of the photosynthetically active organs and the phenology of plants can also be key factors for the survival in cemeteries. They evaluated the occurrences and the reproductive success of a rare dry grassland specialist plant, *Sternbergia colchiciflora*, which has been known from cemeteries of the Pannonian Basin (Central Europe) for centuries. They found that cemeteries provide proper habitat conditions and act as grassland refuge for the species. This is probably mainly possible due to the peculiar phenology and the small stature of this species. Firstly, it is characteristic for the annual life cycle of the plant to develop its aboveground organs out of the main mowing season (from September to May). Secondly, due to its small stature, the plant has a high chance not to be damaged by motorised mowing. Thirdly, the species can tolerate a partial loss of its assimilation surface (e.g. leaves) and thus generate mature fruits even if it has been damaged by mowing. Following this relevant and promising studies, it would be timely and important to study the relationship between plant functional traits and their survival rates in burial sites.

5.2. Cemeteries as small habitat islands and the ecological trap effect

(7) There are currently no studies that would quantify the biotic diversity at the landscape level (Barrett and Barrett, 2001). Additional researches in the subject would be timely since large biodiversity clearly exists in cemeteries, but their importance at larger scales is unclear. Moreover, cemeteries might also act as ecological traps for certain living organisms in a highly fragmented landscape, but whether this is actually the case or not remains to be clarified. Another human-influenced habitat type, namely roadside verges, has been proven to act as an ecological trap: A research on three orchid species (*Himantoglossum* spp.) studied in eight European countries (Fekete et al., 2017) revealed that the direct proximity to roads has a negative impact on the reproductive success. This result indicates that roadside verges are habitats that are suitable for survival, but unfavourable for reproduction, and thus ecological traps. The authors suggest that moderate mowing of the verges (which suppresses woody vegetation) may increase the chance of establishment and survival of flowering plants. As they are both anthropogenically influenced habitats with similar habitat conditions, probably can be set in parallel and applies to cemeteries as well, and habitats maintained by timely and appropriate mowing may in general be favourable to certain organisms of burial sites.

Although the small islands of cemeteries might not necessarily act as ecological traps, man-made constructions, so also cemeteries often distract certain organisms: Horváth et al. (2007) observed that black gravestones attracted five species of dragonflies in cemeteries, and the insects showed the same behaviour in front of the graves as they would near water. The

Table 1
Studied organisms listed in the reviewed papers. The figures in parentheses represent the number of studies available for a given country.

Organism	Country				
Beetles	Turkey (1)				
Orthoptera	Singapore (1)	United Kingdom (1)			
Dragonflies	Hungary (1)				
Snails	Turkey (1)	Latvia (1)			
Birds	Philippines (1)	Slovakia (2)	United States (1)	Poland (1)	Multi country (3)
Lichens	United Kingdom (1)				
Mycobiota	United Kingdom (1)				
Bryophtyes	Poland (1)	Turkey (1)	New Zealand (1)		
Single plant species	Turkey (1)	United States (1)	Australia (2)		
Medicinal & aromatic plants	Israel (1)	Pakistan (1)	Poland (1)		
Orchids	Albania (1)	Australia (1)	Turkey (9)		
Alien vascular plants	Greece (1)	Poland (2)	Romania (1)	United States (1)	
Vascular plants	Australia (6)	Hungary (2)	India (1)	Morocco (1)	Pakistan (1)
Vascular plants	Poland (8)	Tunisia (1)	Turkey (1)	United States (8)	
Phytosociology/Vegetation	Pakistan (2)	Slovenia (1)	Turkey (1)	United States (1)	
Multi-taxon	Germany (2)				

authors suggest that if females attracted to the black gravestones oviposit on them, the gravestones may constitute ecological traps for dragonflies.

5.3. Perspectives for conservation

(8) Cemeteries are usually discrete, small-scale habitats, but as this review highlights, they are often of significant value in guarding different organisms, so they might even function as 'stepping stones' for many species. Several surveys have studied the role of disjoint habitats in the migration of different animal species between populations (e.g. Breckheimer et al., 2014). (9) One of the main conclusions of the reviewed studies is that in order to preserve the natural values of sacred burial places, in certain cases the effort should focus on restoring the religious devotion and the traditional lifestyle of the local population. Therefore, all local customs and rituals should be retained and supported by the policy makers. The significant biodiversity at sacred burial grounds documented worldwide highlights the importance of customs in maintaining elements of the landscape for centuries, while currently their existence is largely threatened by changing demands of the modern world. According to Dudley et al. (2009), the various holy places are the oldest effective 'institutions' for the protection of habitats. They suggest that there are many cemeteries, sacred groves etc. within areas protected by law, but most sacred habitats around the world are forming a largely unrecognised network of habitats 'in shadow'. However, sometimes they function even better for wildlife conservation than some legally protected areas. Therefore, the initiative of Teklehaimanot et al. (2001), whose main goal was (besides the in or ex situ conservation of the remaining 50 churchyard fragments with high biodiversity in Central and Northern Highland regions of Ethiopia) that the '*Biodiversity conservation of ancient church and monastery yards in Ethiopia*' should be highly regarded. Also, according to D'Alessandro (2010), the 'Short Pioneer Cemetery Prairie' in the state of Illinois could survive for centuries because the respect for the historic cemetery was stronger than mining interests. Note, however, that the author also emphasises that this is not always true, i.e., local people can also be motivated by the financial support of the economically interested persons to exploit a given natural value.

(10) It is suggested that active conservation intervention in natural burial sites should only take place if the protection of the site cannot be ensured otherwise, e.g. when a change in religious values results in a discontinuation of traditional habitat management methods. This strategy is also favourable in view of the limited capacity of policy makers to manage conservation issues. An alternative proposition was made by Mallarach and Papayannis (2010): Where appropriate and justified, paid caretakers could continue the desired integrated management practices in cemeteries, churchyards and other sacred places.

5.4. Management of cemeteries

(11) Almost all publications listed in this review discussing the threatening factors that directly or indirectly affect cemeteries and churchyards suggest that traditional management methods should be favoured for the maintenance of natural values of cemeteries, while religious traditions and beliefs also help to protect them. However, studies on the direct effect of management practices on natural values of cemeteries are completely missing (Barrett and Barrett, 2001), and knowledge of indirect effects is strongly limited (Molnár V. et al. 2017a).

Nowadays, the prevalence and intensity of human activities and constructions that reduce the size of the various green areas in cemeteries are increasing worldwide (e.g. Cooper, 1995; Hamilton, 2008; Hewitt, 2013). Probably a gentler and more appropriate management of cemeteries, with special emphasis on the needs of various organisms (e.g. proper lawnmowers (Molnár V. et al., 2018), manual and electric mowing at regular intervals (Anderson et al., 2011), shrub removal only in

justified cases and outside the vegetation period (Molnár V. et al. 2017b), leaving old dead trees in cemeteries for saproxylic insects (Atay et al., 2012) etc.), would result in higher biodiversity in the long run. For example, Baker (2005) suggests that a diverse churchyard surveyed in Shropshire should be managed as a hay meadow by cutting the grass only once or twice a year in the late summer. Her recommendation is further supported by the study of Gardiner et al. (2011), who reported two grasshopper species to be present in higher abundances in churchyards of Essex, England, than in short grasslands nearby. According to McBarron et al. (1988), mulching in the cemetery of Liverpool, Australia, should be limited in order to maintain the natural conditions, while the mild and controlled application of fire instead of using herbicides is considered to be suitable to control the weeds. Unfortunately, renunciation of these management methods seems incompatible with some of modern society's needs. Although maintaining the natural habitat patches is essential, occasional pruning of woody vegetation should also be conducted in certain regions (Frosch et al., 2016). The latter authors studied the vegetation and flora in 86 holy places (including cemeteries) in northern Morocco. The most valuable plant species were associated with the presence of woody vegetation or a partial or even total absence of grazing; however, only 20% of the surveyed sites were closed forests. Also, in two studies from Europe (Tryjanowski et al., 2017; Morelli et al., 2018b), it was found that bird species richness positively correlated with site area, tree coverage and age of trees in cemeteries; moreover, several bird species often recognised as urban avoiders can be detected in cemeteries.

(12) Local people should consider substituting non-native ornamental plants, especially those with invasive tendencies, by unharmful, preferably native species. According to researchers, it would be worth considering the exclusive use of native species and the omission of non-native ornamental plants in order to protect the natural values of burial places. This might favour to the natural species composition of cemeteries, which can change relatively fast as time goes by: Hewitt (2013) revisited two cemeteries previously surveyed by Tony Price at 1979 in Australia, to examine the condition of the vegetation of the sites. He concluded that the proportion of alien species had increased over time, but the boundaries of the natural habitat patches remained unchanged. It is also important to mention that obviously clearing a territory of invasive species promises partial or full regeneration of the original habitat in the case of cemeteries. For instance, removal of the invasive *Lonicera maackii* from an old cemetery in central Kentucky resulted in a rapid recolonisation of the habitat by annual and perennial native plant species (Thompson and Poindexter, 2011).

(13) There are also extreme suggestions of appropriate management methods, also indicating that burial places are special habitats with sometimes special habitat needs. For instance, Ruch et al. (2014) recommended that based on the requirements of prairie plants, the use of periodically constructed (controlled) fires is necessary to further maintain the species composition and structure of the area. It is obvious that for the vast majority of the human society, setting up fires in cemeteries would be morally and aesthetically unacceptable or at least doubtful in most regions of the world. However, a management method that seems unusual at first might sometimes be the ultimate and fastest solution for conserving the natural patches of vegetation in cemeteries. Hence caretakers should consider different options in order to choose the best management methods from both a moral and a practical point of view.

5.5. Involvement of local communities in the protection and monitoring of biodiversity of cemeteries

(14) The best and most popular cemeteries are already widely known in amateur naturalist communities and subjects of special consideration. A good example is the British cemetery of Kerkyra (Corfu), embedded in an urban environment, where professional and amateur orchid enthusiasts find several orchid species every year, and the cumulative orchid species number is above 30 (Seaton et al., 2015). Progressive and good examples for conserving the locally most prominent cemeteries and churchyards are the “churchyard/cemetery preserves” in the UK; (Zisenis, 1998). In Illinois, United States, cemetery protection has also been legally solved by establishing “Prairie Cemeteries and Savannahs” in several counties. They function as nature preserves and are intended to safeguard the original vegetation (Moorehouse and Hassen, 2004). Involving communities is essential for the effective and respectful conservation of both natural and cultural values of burial places. Groups promoting the wildlife of burial places regularly discover that they face normative questions that have no scientific answers (Cooper, 1995). As ethics is a communal matter, we need to develop our social skills and mechanisms as well in order to develop our attitude towards such sensitive cases like the conservation of natural values in cemeteries and churchyards.

6. Conclusions

The role of cemeteries and churchyards in biodiversity conservation in the close proximity of urban areas is unquestionable in the new era. We found that besides their religious function, cemeteries and churchyards have a considerable conservation role, as even in heavily transformed landscapes they often act as refuges for the populations of rare and endangered species. However, in parallel with changes in the social attitude towards sacred places and the erosion of traditional taboos, the management of these natural refuges has also been altered worldwide. As conservation and spirituality is tightly interwoven in cemeteries, we suggest that restoring the eroded social and spiritual traditions of local communities entails the conservation of these often last healthy and natural habitat patches of urban areas.

Declarations of interest

None.

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Appendix A. Supplementary data

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