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Spontaneous vascular flora of the historical monumental cemetery of Modena (N-Italy)

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Abstract

The first floristic study of the historical monumental cemetery of San Cataldo in Modena (N-Italy) is presented. The research was performed in the period 2019–2022, considering only spontaneous individuals growing within the historical area (4.8 ha). A total of 266 taxa (species and subspecies) was found, of which 1 new for the flora of Italy (*Malus* ×*robusta* 'John Downie'), 2 new for the administrative region of Emilia-Romagna (*Calocedrus decurrens* and *Salvia haematodes*) and 1 new for the province of Modena (*Epilobium ciliatum*). Therophytes prevail (37.6%), followed by hemicryptophytes (31.6%), phanerophytes (16.2%) and geophytes (11.7%). The chorological spectrum is dominated by Eurasian species (32.0%), followed by Mediterranean (26.3%), Cosmopolitan (24.8%), Boreal (6%) and N-American (4.5%) ones. Allochthonous species are 16.5% of the list, with neophytes always prevailing over archaeophytes (28 *vs.* 9 species). Invasive species are 67.8% of the neophytes; on a regional scale they are 1.5% of the list. Protected species are 2.6% of the total; 3 of them are internationally protected and 2 are included in the red list of Italian flora. This study confirms the great biological richness of urban environments and the potential of historical cemeteries as a refugium for the conservation of species that have become rare, endangered or infrequent at a regional or national level, because of the heavy human impact on the territory.

Keywords

Allochthonous species, historical cemetery, plant biodiversity, protected species, ruderal species, urban ecosystem

Introduction

In Europe, monumental cemeteries are intended as those with «a planned and grandiose layout […] articulated by a web of axial avenues and punctuated by major buildings, such as chapels, gateways and porticoes»: in other words, they are cemeteries where «architecture must prevail over the landscape», in contrast to the so-called garden (or picturesque) cemeteries (Malone 2017). In Italy, they are defined as burial grounds characterised by remarkable monuments of historical-artistic relevance and historical-cultural value as sites of collective memory, linked to important historical episodes or specific religious ambits. These cemeteries are ascribable to the category of the so-called «cultural landscapes», also thanks to given landscape features (Regione Emilia-Romagna 2022). They are typical of Mediterranean Europe, in countries of Latin culture, and are often inspired by the architectonic structure of the medieval cloister, by the Italian garden and by the Roman monumental tradition (Bontempi 2011; Malone 2017). They often have a high artistic value, since tombs are adorned with elaborate sculptures (at times paintings, too) that can be the work of famous artists. Certain monumental cemeteries, such as the Cimitero della Certosa of Bologna, the Cimitero Monumentale di Milano or the Cimitero Monumentale di Staglieno in Genoa, are true open-air museums, visited, in the past, by writers and poets like Chateaubriand, Byron, Stendhal, Mommsen and Dickens in the course of their Grand Tour (Felicori 2006; Felicori and Zanotti 2006). Most of these cemeteries were conceived and built after the Décret Impérial sur les Sépultures, promulgated by Napoleon on June 12th, 1804, to solve the hygiene problems related to the custom of inhuming the dead within the city walls, that for centuries had been the practice in the entire continent (Malone 2017). Therefore, these sites are generally 150–200 years old (Barban 1928; Felicori 2006; Marino 2014; Malone 2017). In Italy, the first one was built in Naples (Poggioreale, 1813–1840), followed by those of Brescia (1815–1856), Cagliari (1827–1829), Turin (1828–1830), Verona (1828–1844), Cremona (1828–1860s) and Genoa (1844–1860s). Nevertheless, some monumental cemeteries pre-date the Napoleonic decree: for example, that of Pisa (Campo Santo), founded in 1278 and described as the first monumental cemetery in Italy (Rovani 1854), will be the model for numerous subsequent cemeteries in Italy and Europe; the ones of Bologna (Certosa, founded in 1801) and Ferrara (1811) both reused pre-existing structures dating from 1334 and 1452, respectively (Malone 2017).

Today, historical cemeteries are of remarkable interest also from an ecological viewpoint, because they can act as a refuge for numerous animal, plant and lichen species (Trzaskowska and Karczmarz 2013; Kowarik et al. 2016; Löki et al. 2019) that elsewhere are rare or extinct owing to the profound human impact on the territory. The floristic diversity of cemeteries derives from geographical, historical, cultural and social factors (Czarna et al. 2007), whereas species richness depends on management type of the various areas; to zones differing by age of foundation correspond diverse biotic communities, well characterised by a peculiar species composition (Kowarik et al. 2016). The partial or nearly total abandonment to which some portions of a cemetery are often

subjected permits the formation of particular habitats, where it is not infrequent to discover rare species that have found a refuge because of the low human disturbance (Czarna and Piskorz 2005; Latini 2007; Sigiel-Dopierała and Jagodziński 2011; Trzaskowska and Karczmarz 2013; Buchholz et al. 2016). Age of the cemetery and religious confession do not seem to have a particular influence on species diversity (Rutkovska et al. 2011). In the long run, the inveterate use of adorning graves with cut flowers or living plants, often exotic, kept in a pot or in the ground, allows them first to naturalise within the cemetery, then spread out and start colonising the territory (Hügin and Hügin 1999; Pyšek et al. 2004; Lazzeri et al. 2013; Bellone et al. 2015). In fact, a strong positive correlation exists between the area occupied by the cemetery and the number of allochthonous species recorded therein (Rutkovska et al. 2011); moreover, some species introduced by Man over time become naturalized and well established in cemeteries, so that they are known as «permanent cemetery species» (*sensu* Czarna 2001 and Czarna et al. 2011, defined as «old» vascular plants, cultivated since many years).

Historical cemeteries can host a great number of autochthonous and exotic vascular plant species, including many that are infrequent in rural zones (McBarron et al. 1988). Nonetheless, studies on the flora and vegetation of cemeteries are still scarce (Šilc 2009) and mostly limited to simple lists of woody species, whereas herbaceous ones are nearly never considered (Stypiński 1978; Dorda 1995; Antkowiak and Heine 2005). In addition, although the potential of cemeteries in the spreading of allochthonous species is not negligible, the first research efforts in this sense are recent and still confined to very few countries (e.g., Bowdler et al. 2002, 2007; Gudžinskas 2005).

In general, interest for the study of cemetery flora can be explained as follows:

- it is a flora that normally develops in mostly anthropogenic habitats, which are, however, similar to natural habitats with moderate disturbance;
- it is possible to thoroughly investigate the presence of exotic species, for whom the cemetery might act as a spreading centre for the surrounding territory;
- it is possible to compare the spontaneous flora of the cemetery with that of the historical centre of the same city, since both are stable environments from an urban viewpoint, albeit very different in terms of quality and intensity of human disturbance;
- it offers an opportunity to increase our knowledge of the auto-ecology of various species and the effects of human influence on other living organisms.

Even though the notable botanical interest of historical cemeteries has been recognized since the 1920s (Rojecka 1934), studies exclusively dedicated to cemeteries built in the XIX century are still very few and often referred to central-eastern Europe or to the Baltic Republics; to our knowledge, no information on monumental cemeteries is available so far. The aim of this work was to perform the first systematic research on the spontaneous flora of one of the most ancient monumental cemeteries in Italy, the Cimitero di San Cataldo in Modena (Avramidou and Maio 2006). The cemetery is renowned because it hosts the tombs of some famous people (such as Enzo Ferrari, founder of the well-known car factory). To date, the entire area has been the object of

simple sporadic observations, which were mostly made during a floristic analysis of the whole province (Alessandrini et al. 2010; Santini et al. 2019). The results will be compared to those obtained in a recent study of the urban flora of the historical city centre (Buldrini et al. 2020), as an ideal continuation and completion of the research on the spontaneous flora of the most ancient part of the city of Modena. A comparison will also be made with studies on other cemeteries in Europe; these are very different, both from a climatic-environmental and physiognomical standpoint, so the comparison will be necessarily made only at a general level.

Materials and methods

Study area: geographical, pedological, and urban context

Modena (44°10.683'N, 10°55.533'E, 35 m a.s.l.) is situated in northern Italy (Emilia-Romagna administrative region, Fig. 1), in a flat territory bordered by the River Secchia westward and the River Panaro eastward. Inhabitants are 185719 (Comune di Modena – Servizio Statistica 2022).

Soils are principally clayey with a small amount of silt, very calcareous and moderately alkaline. From a geographical standpoint, they are part of a plain with alluvial cover and are situated on transition deposits joining valleys and natural embankments. These soils are very deep, with good oxygen supply for plant roots; their texture is moderately fine at the surface and they do not present any constraints for plant growth. According to the Soil Taxonomy, they are classified as Fluventic Ustochrepts fine-silty, mixed, mesic (Guermandi and Preti 1993).

The study site is the Cimitero di San Cataldo, a historical monumental cemetery in the northwestern outskirts of the city (Fig. 1A, B), whose name derives from the ancient church and convent of San Cataldo, adjacent to the cemetery; it is situated *ca*. 2 km northwest of the ancient city walls (Avramidou and Maio 2006).

Study area: climate

Modena is about 100 km from the Adriatic Sea and has a typically continental climate, with rigid winters, warm summers, often very high atmospheric humidity and absence of wind. Especially during winter, and particularly in suburban areas, the formation and persistence of fog is frequent, normally associated to anticyclonic periods. Summer is generally humid, hot and muggy, with stormy precipitation (Lombroso and Quattrocchi 2008; Alessandrini et al. 2010).

During the climate reference period 1991–2020, average monthly temperatures showed a minimum in January (4.3 °C) and a maximum in July (26.1 °C); during summer it is frequent to exceed 30 °C, not rarely for many consecutive days, with peaks close to 40 °C (Lombroso and Teggi 2017, 2018; Lombroso et al. 2019). Average annual temperature is 15.1 °C; average minimum temperature is 11.6 °C and

average maximum temperature is 18.6 °C (Lombroso et al. 2022). In the surrounding suburban areas, the urban heat island raises average monthly temperatures by 1.4 °C in the daytime and by over 6 °C at night, in particular during peaks of heat and cold (Magli et al. 2015). On average, the days with minimum temperature lower than 0 °C are 16.9 per year and those with maximum temperature lower than 0 °C are 1.2 per year. The average relative humidity is 61.7%, variable from 45.4% in July and 79.5% in November–December. Annual precipitation is 691.4 mm, with 114 rainy days per year; spring and autumn are the wettest seasons. Snow precipitation, on average, is 29.5 cm per year (Lombroso et al. 2022; Lombroso and Despini unpubl. data). In the years 2019–2022, when the floristic research was performed, significant differences were recorded with respect to the above-mentioned average climatic conditions (Lombroso et al. 2020, 2021, 2022): anomalous rainfall values (+37.8% in 2019, -47.0% in 2021, -23.8% in 2022) and higher average annual temperatures (+1.1 °C in 2019, +1.7 °C in 2022); snowfall never exceeded 16 cm per year.

Floristic research: the zones considered

To investigate the flora of all historic and monumental parts of the Cimitero di San Cataldo, we explored 4 zones differing in surface area, age of foundation, and frequency of visits (Fig. 1A): in the Catholic cemetery, we considered the monumental part (zone 1a – Fig. 1D), the ancient tombs disposed all along the southern perimeter wall of the cemetery (zone 1b), and the grasslands of the ancient ossuary (zone 1c – Fig. 1E); in the Jewish cemetery, we took into account the entire area (zone 2 – Fig. 1F). All of the green areas within the cemetery complex are mowed on average 7–8 times per year, depending on the season's weather trend; even in case of exceptionally snowy winters or rainy summers, mowing frequency never exceeds 10 times per year (Bartolamasi *in verbis*).

The Catholic cemetery

The first construction of a burial site in the area of San Cataldo, outside the city walls, dates back to 1773: it is one of the very first extraurban cemeteries of Italy and Europe (Bertuzzi 1990; Avramidou and Maio 2006; Malone 2017). The project realisation, attributed to Giovanni Francesco Zanini, was very complex due to the characteristics of the area, namely the fact that the ground did not permit adequate degradation of organic matter and effective drainage of rainwater. The first cemetery was built with a rectangular base (86×61 m) and was surrounded by an embankment *ca*. 3.5 m high. Its style, inspired by the Enlightenment criteria of that age, was quite anonymous and impersonal, without a particular architecture or any ornament to the memory of the dead (monuments and chapels were added from 1778 onwards – Malone 2017). This site remained in operation for decades, until in 1850 the Municipal Council of Modena decided to refurbish it; the project was developed by the architect Cesare Costa. When the cemetery was reopened, albeit partially, in 1864, it was 51000 m² wide and its construction was still incomplete.

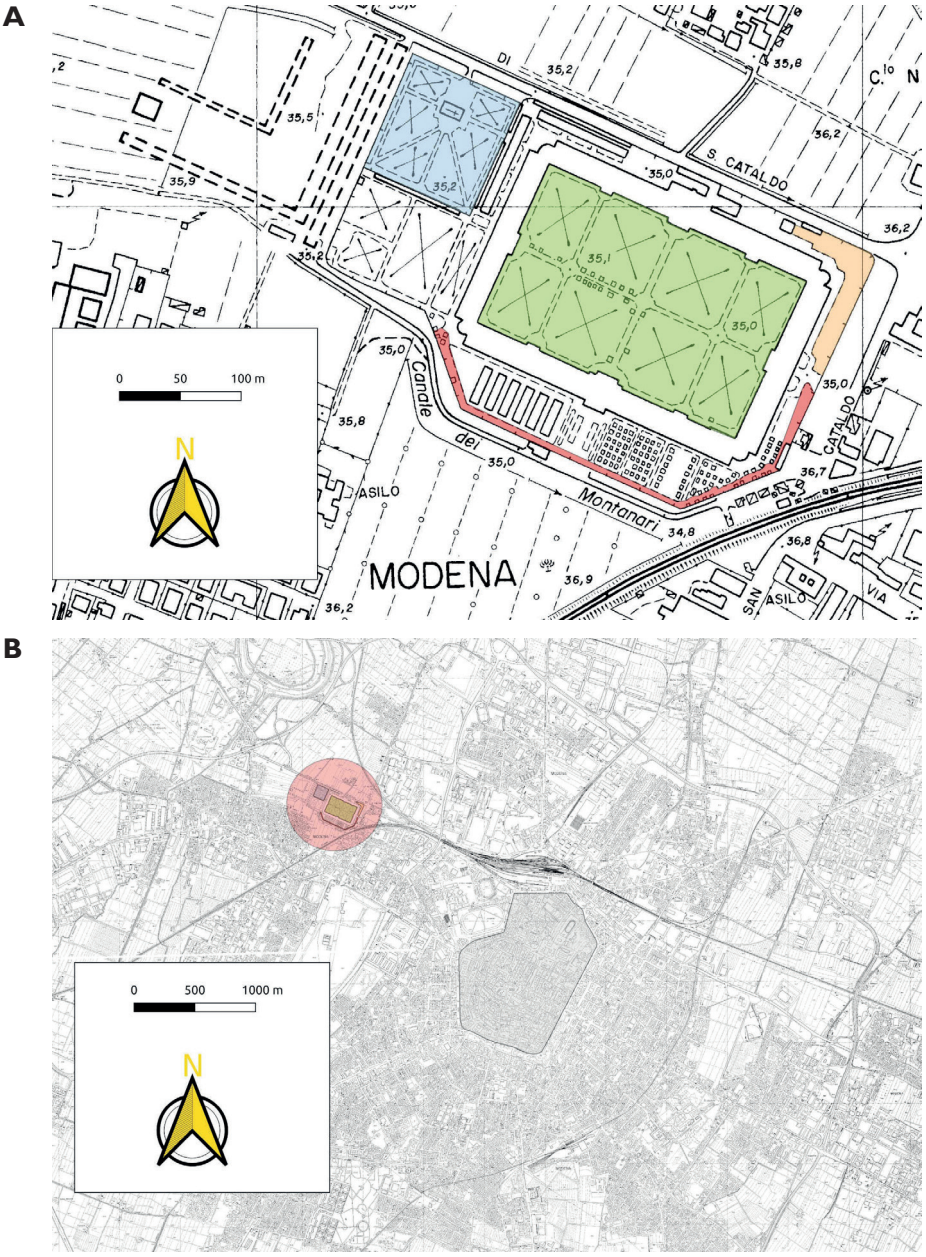

Figure 1. The cemetery area of Modena **A** position of the areas investigated (green: Catholic cemetery, monumental part – zone 1a in the text; red: Catholic cemetery, ancient tombs disposed all along the southern perimeter wall of the cemetery complex – zone 1b in the text; orange: Catholic cemetery, grasslands of the ancient ossuary – zone 1c in the text; blue: Jewish cemetery – zone 2 in the text) **B** position of the cemetery area with regard to the historical city centre (in gray) **C** position of Modena (black dot) within Italy **D** view of the Catholic cemetery in the monumental part **E** view of the grassland of the ancient ossuary in the Catholic cemetery **F** view of the Jewish cemetery. The cartographic base of parts **A** and **B** derives from the Carta Tecnica Regionale dell'Emilia-Romagna (scale 1:5000), with modifications.

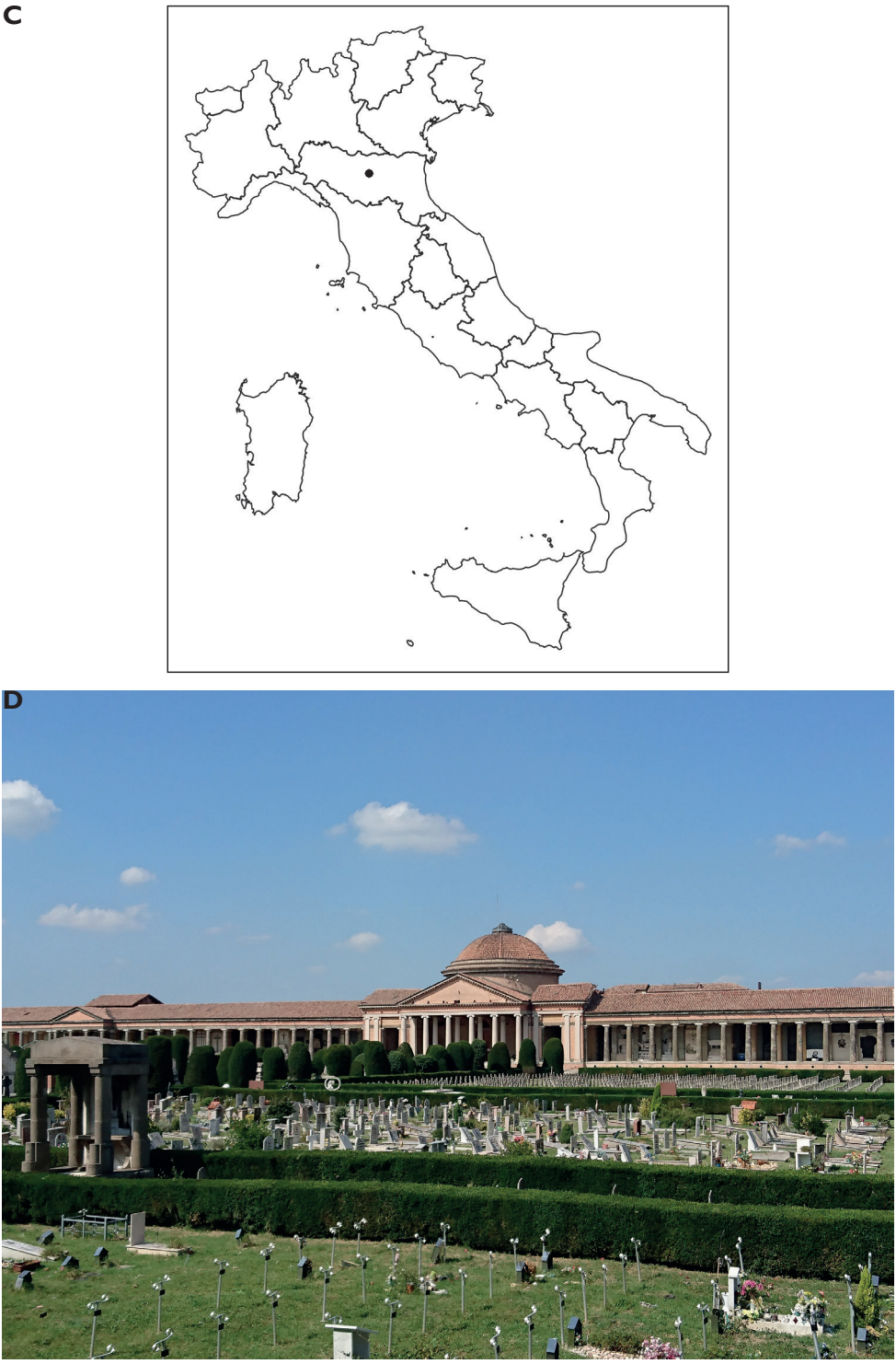

Figure 1. Continued.

E

F

Figure 1. Continued.

During the 1930s, other works on the columns of the portico were carried out, then others in 1948 and again in the 1960s and 1970s, with the construction of new external galleries in the northern and eastern sides and a refurbishment of the southern access. Finally, the cemetery acquired the monumental aspects of funerary architecture, that should assure the survival of the dead in the collective memory. In fact, it is rich in statues and artworks adorning tombs, that make it a true open-air museum (Felicori and Zanotti 2006).

Three areas were investigated in the Catholic cemetery:

- zone 1a (33000 m²) – the area is delimited by the portico and is subdivided into eight rectangular sectors disposed in two rows, intermixed with gravel driveways. Many of these sectors are currently in use, therefore subjected to quite frequent works; the remnant, not occupied by tombs or dedicated to the soldiers who died in the First World War, are maintained as lawns;
- zone 1b (2500 m²) – this area is occupied by the tombs disposed all along the southern perimeter wall of the entire cemetery complex, outside the monumental part described above; they often are quite old (late XIX-early XX century), with a certain show of monumentality and, in many cases, abandoned;
- zone 1c (2560 m²) – this area comprises the grasslands of the ancient ossuary, scarcely visited and dating back to the late XVIII century, i.e. at the foundation of the entire cemetery complex (Avramidou and Maio 2006).

The Jewish cemetery

The present Jewish cemetery of Modena (zone 2) substitutes the original one, dating back to the XVII century, which was situated a few hundred meters outside the city walls, in a zone that is now densely urbanised. In 1900, the Municipal Council approved the project of the new cemetery, in an area adjacent to the Catholic one; the cemetery itself, built and paid by the local Jewish community, was opened in 1903. Bodies and tombstones were then transferred here and the old cemetery was closed and subsequently dismantled (Avramidou and Maio 2006).

In this cemetery, little or nothing has changed since its opening. It does not have the monumental character of the Catholic one, consists of a square-shaped area of 10000 m², surrounded by a perimeter wall and divided into six parts (two rectangular ones practically without tombs, and four larger ones, one of them nearly devoid of tombs), intermixed with narrow gravel driveways. Many other tombs are situated all along the perimeter walls. In an off-centre position there is a small building in neoclassical style, used for funeral rites, designed by the engineer Eugenio Guastalla. All six parts of the cemetery are maintained as lawns (Avramidou and Maio 2006).

Study method

The floristic surveys were carried out in the period 2019–2022, spread over nine months of observation per year (during the vegetative season from February to October); two surveys per month were generally performed (Gianaroli 2020 and unpubl. data).

Data from occasional observations performed in past years (from April 1998 to April 2015) and data from herbarium samples preserved in the Erbario dell'Orto Botanico di Modena (MOD), which were already published by Alessandrini et al. (2010), were also considered.

Only spontaneous vascular plant species were taken into account. Individuals growing in the grasslands, under or within the hedgerows or other ornamental plants, among or over the tombstones, on the gravel driveways, in the cracks of sidewalks or walls up to a height of 1 m above ground level were considered (further details are reported in Table 1). Species introduced by Man for ornamental purposes were taken into account only if they had spread spontaneously, since they can be regarded as exotic cultivated and naturalized species (*sensu* Viegi et al. 1974). All areas subjected to works during the study period (addition of new tombs, refurbishment of existing ones etc.) were excluded from our analyses, to record only the species with a more or less stable presence within the historical part of the cemetery.

Whenever possible, plant species were identified directly in the field; otherwise, a sample was collected and examined under a stereomicroscope (Nikon C-PS SMZ645). Identifications were performed following Zangheri (1976), Rothmaler (2000), Eggenberg and Möhl (2015), Pignatti et al. (2017–2019), Lepší et al. (2019). In particular, *Malus* ×*robusta*

Table 1. Growth environments considered in this study, with a description of their characteristics and plant cover.

Growth environment	Explanation and kind of plant cover
Grasslands	grasslands and lawns, regularly mowed, with or without tombs (plant cover: continuous and dense)
Fissures	fissures and cracks between the stone slabs composing the monumental tombs, or in the sidewalks (plant cover: isolated, sporadical individuals, in general)
Sand	sandy sediment at the base of the brick walls, due to the degradation of the mortar and the bricks themselves (plant cover: isolated individuals)
Under the hedgerows	under the hedgerows, or under the crown of other woody plants cultivated for ornament (plant cover: at places continuous, at places discontinuous)
Within the hedgerows	within the hedgerows, or within the crown of other woody plants cultivated for ornament (plant cover: single individuals emerging from the crown of the hedgerow or ornamental woody plant, but whose roots are at the foot of the hedgerow/ornamental woody plant itself)
Soil from the flowerbeds on the grave closing slabs	soil (not rarely old) from the flowerbeds on the slabs closing the graves, both in monumental tombs and in graves on the ground (plant cover: continuous, sometimes nearly dense)
Clay between adjacent tombs	clay between two adjacent tombs, not or rarely mowed (plant cover: nearly continuous, but not necessarily dense)
Gravel driveways	in the gravel driveways, or at their margins (but not on the slope of the grasslands or lawns, which is formed by the rise of the ground in the burial areas) (plant cover: discontinuous, but sometimes relatively dense)
Backfill	backfill, sometimes mixed with old soil, of the large flowerbeds where hedgerows and ornamental trees are grown (plant cover: discontinuous, at places sparse)
Clay	clay in the driveways or at the margins of grasslands and lawns (on the slopes) (plant cover: sparse)

was identified according to Stace (1997), Johnson and More (2006), Sterry (2007), Brickell (2012) and Wöhner et al. (2014). Life forms and chorotypes were attributed according to Pignatti et al. (2017–2019); in view of the analyses, chorotypes were subsequently grouped into macro-chorotypes *sensu* Poldini (1991), Tomaselli and Gualmini (2000) and Alessandrini et al. (2010). Nomenclature, taxonomy, distribution and status (native, archaeophyte, neophyte, cryptogenic) of the species follow Bartolucci et al. (2018) and Galasso et al. (2018) and their updates periodically appearing in the Portal to the Flora of Italy (2022; see also Martellos et al. 2020). Protection level at a national and regional scale was attributed according to Rossi et al. (2013, 2020) and Regione Emilia-Romagna (2018).

To better characterize the single zones examined, we calculated the number of growth environments detected in each one, Pearson's correlation coefficient between species number and number of growth environments for each area and Jaccard's similarity index for all the areas.

Results

The taxa (species and subspecies) recorded in the entire area examined were 266 (see Suppl. material 1), of which 129 were found in zone 1a, 100 in zone 1b, 61 in zone 1c and 180 in zone 2. The taxa found in the three areas belonging to the Catholic cemetery summed up to 205; 118 out of 205 taxa (57.6%) were also present in the Jewish cemetery. Of the 266 taxa, 176 (66.2%) were already included in the flora of the historical centre of Modena.

These 266 taxa belong to 66 families and 175 genera. The most represented families are Asteraceae (37 taxa), Poaceae (35), Brassicaceae (16), Fabaceae (14), Rosaceae (13), Caryophyllaceae (12) and Lamiaceae (11); the others include up to 10 taxa each. The most represented genera are *Crepis*, *Galium*, *Ranunculus* and *Trifolium* (each one with 5 taxa), *Erigeron*, *Geranium*, *Lepidium*, *Poa* and *Veronica* (4 taxa), *Allium*, *Anisantha*, *Cerastium*, *Convolvulus*, *Epilobium*, *Equisetum*, *Euphorbia*, *Lactuca*, *Oxalis*, *Quercus*, *Salvia* and *Setaria* (3 taxa).

Of the total number of taxa recorded, 1 is new for the flora of Italy (*Malus* ×*robusta* (Carrière) Rehder 'John Downie', casual alien), 2 are new for the flora of Emilia-Romagna (*Calocedrus decurrens* (Torr.) Florin, casual alien, and *Salvia haematodes* L., native to Italy) and 1 is new for the flora of the province of Modena (*Epilobium ciliatum* Raf., naturalized alien on a national and regional scale). They were found in zone 1a (*E. ciliatum*), zone 1b (*C. decurrens*), zone 1c (*M.* ×*robusta* 'John Downie') and in all areas (*S. haematodes*), respectively.

Draba verna L. subsp. *verna* is the only taxon collected in the cemetery that is also present in the Erbario dell'Orto Botanico di Modena (*Leg*. A. Vaccari, April 1883, «Muri del cimitero di S. Cataldo presso Modena», in MOD), later confirmed during field surveys. On the contrary, the following species, recorded in past years, were not confirmed during this research: *Allium pallens* L., *Ranunculus sardous* Crantz, *Salvia virgata* Jacq. (all three in the Catholic cemetery) and *Ranunculus acris* L. subsp. *acris* (Jewish cemetery), whose findings date back to the period 1999–2014.

Concerning the growth environments (Table 1), most taxa were found in grasslands and gravel driveways (158 and 108, respectively), followed by fissures and cracks (73), soil from the flowerbeds on the grave closing slabs (55), and backfill (54); the other habitats hosted no more than 30 taxa each. The highest environmental variety was found in zone 1a, the lowest in zone 1c (Table 2). The correlation value between number of taxa recorded in each zone and number of growth environments is 0.709.

The life form spectrum (Fig. 2) is always dominated by annual species (therophytes), forming up to 40.0% of the total list (entire study area 37.6%), followed by hemicryptophytes, variable between 30.0 and 32.7% (entire study area 31.6%), phanerophytes, variable between 11.7 and 20.0% (entire study area 16.2%) and geophytes, variable between 10.6 and 13.3% (entire study area 11.7%). Chamaephytes and helophytes are a very marginal presence (entire study area 2.6% and 0.4%, respectively), not observed in all of the sectors. The vast majority of the flora is, therefore, composed

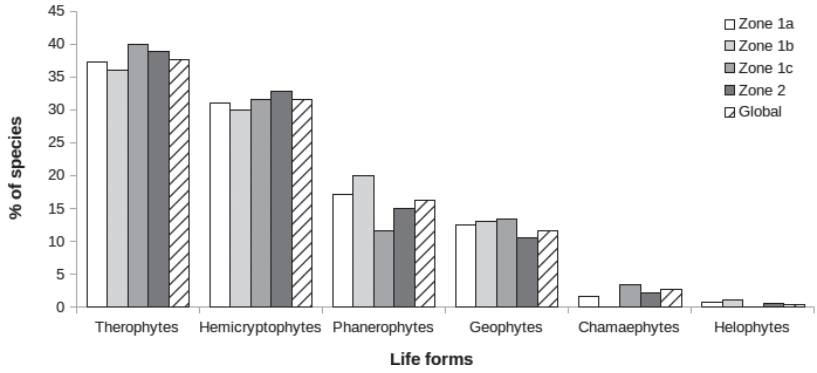

Figure 2. Life form spectrum of the study area. Zone 1a: Catholic cemetery, monumental part; zone 1b: Catholic cemetery, ancient tombs disposed all along the southern perimeter wall of the cemetery complex; zone 1c: Catholic cemetery, grasslands of the ancient ossuary; zone 2: Jewish cemetery.

Table 2. Growth environments in each of the cemetery sectors analysed during this study. Zone 1a: Catholic cemetery, monumental part; zone 1b: Catholic cemetery, ancient tombs disposed all along the southern perimeter wall of the cemetery complex; zone 1c: Catholic cemetery, grasslands of the ancient ossuary; zone 2: Jewish cemetery.

Growth environment	Zone 1a	Zone 1b	Zone 1c	Zone 2
Grasslands	x		x	x
Fissures	x	x	x	x
Sand	x			
Under the hedgerows	x		x	x
Within the hedgerows	x	x		x
Soil from the flowerbeds on the grave closing slabs	x	x		x
Clay between adjacent tombs	x	x		x
Gravel driveways	x	x		x
Backfill	x	x		
Clay	x	x	x	x
Total number	**10**	**7**	**4**	**8**

by herbaceous species, with values comprised between 80.0% in zone 1b and 88.3% in zone 1c (entire study area 83.8%).

The chorological spectrum (Fig. 3) is always dominated by widely distributed types. The prevailing species are Eurasian, Mediterranean and cosmopolitan, with values ranging between 31.0 and 35.0% (entire study area 32.0%), 19.0 and 30.0% (entire study area 26.3%) and 21.7 and 36.2% (entire study area 24.8%), respectively.

Allochthonous species occurred in all sectors analysed, with values comprised between 9.8% in zone 1c and 22.0% in zone 1b; in the entire study area they were 16.9% of the list (Table 3). Neophytes were always dominant, with values comprised between 47.4 and 100% of the total number of exotic species (in zones 1a and 1c, respectively); in the entire study area they composed 62.2% of the exotic species list. Among neophytes, invasive species made up 67.8% of the total, but the species with an invasive behaviour also on a regional scale were limited to 4 out of 28, i.e., *Ailanthus altissima* (Mill.) Swingle, *Erigeron canadensis* L., *Lonicera japonica* Thunb. and *Vitis* ×*koberi* Ardenghi, Galasso, Banfi & Lastrucci. Archaeophytes were few (9 species, i.e. 3.4% of the total floristic list); most of

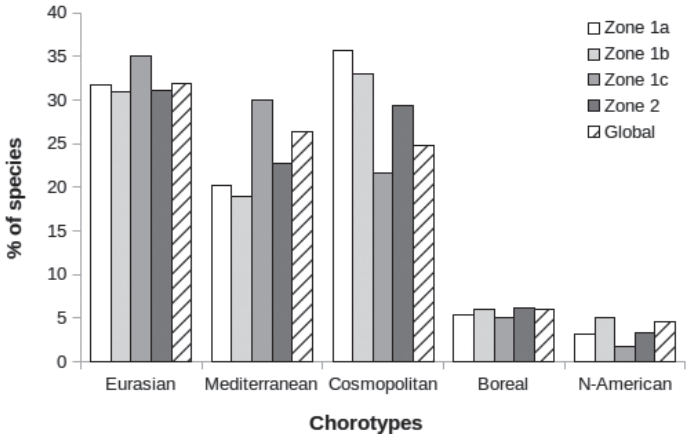

Figure 3. Chorological spectrum of the study area. Chorotypes with less than 3% of species are omitted. Zone 1a: Catholic cemetery, monumental part; zone 1b: Catholic cemetery, ancient tombs disposed all along the southern perimeter wall of the cemetery complex; zone 1c: Catholic cemetery, grasslands of the ancient ossuary; zone 2: Jewish cemetery.

Table 3. Number of allochthonous species recorded in this study, subdivided by area and category. Zone 1a: Catholic cemetery, monumental part; zone 1b: Catholic cemetery, ancient tombs disposed all along the southern perimeter wall of the cemetery complex; zone 1c: Catholic cemetery, grasslands of the ancient ossuary; zone 2: Jewish cemetery.

Species category	Zone 1a	Zone 1b	Zone 1c	Zone 2	Global
Archaeophytes	5	3	0	8	9
Neophytes	9	13	6	16	28
Cryptogenic	5	6	0	6	8
Total number	**19**	**22**	**6**	**30**	**45**

them were casual or naturalized species on a national scale (the only invasive archaeophyte was *Sorghum halepense* (L.) Pers.). Cryptogenic species (8, globally) were never invasive. None of the allochthonous species was frequent or abundant: only *Erigeron sumatrensis* Retz. and *Euphorbia prostrata* Aiton were relatively common, but populations were always composed by a modest number of individuals (5–10 or less) or even isolated plants.

The species classified as endangered at a national level were 2 (*Allium roseum* L. subsp. *roseum* and *Bellevalia romana* (L.) Sweet, both assessed as «LC» – least concern), those protected at a regional level were 5 (*Anacamptis morio* (L.) R.M.Bateman, Pridgeon & M.W.Chase, *Ilex aquifolium* L., *Orchis purpurea* Huds., *Spiranthes spiralis* (L.) Chevall. – Fig. 4 – and *Taxus baccata* L.). It should be pointed out that *A. morio*, *O. purpurea* and *S. spiralis* are also protected at an international level (CITES), since

Figure 4. Flowering individual of *Spiranthes spiralis* (L.) Chevall. in the grasslands of the Jewish cemetery (zone 2). The plant is ca. 15 cm high.

all species ascribed to the Orchidaceae are listed among those for which international trade is forbidden. Globally, the 7 species mentioned above account for 2.6% of the total list. In zone 2, 5 red-listed species were found (*A. roseum* subsp. *roseum*, *A. morio*, *B. romana*, *S. spiralis*, *T. baccata*), in zone 1a 2 (*A. roseum* subsp. *roseum*, *I. aquifolium*) and in zone 1c 1 (*O. purpurea*).

The similarity *sensu* Jaccard of the zones considered is as follows: 1a–1b: $J = 0.316$; 1a–1c: $J = 0.132$; 1a–2: $J = 0.373$; 1b–1c: $J = 0.135$; 1b–2: $J = 0.353$; 1c–2: $J = 0.137$.

Discussion

This study examines, for the first time, the spontaneous vascular flora of a European historical monumental cemetery. In Europe, in fact, the few surveys conducted so far on cemetery flora concern «normal» burial grounds, without monumental features or with any particular visual or aesthetic impact. The sole European country where cemeteries are quite well studied from a botanical viewpoint is Poland (Löki et al. 2019; Moysiyenko et al. 2021).

In our study, species number in the single areas was lower than that recorded in other urban cemeteries (e.g. from 171 to 218 species in four cemeteries of the area of Poznań, but the areas covered generally were 6–8 ha and only in one case 0.25 ha; cfr. Czarna et al. 2011); it is, however, proportionally much higher if we consider the entire study area: 266 species on a 4.8 ha surface. Nonetheless, the comparison makes sense only if differences in climate, environmental variety, richness of the national flora and kind of plant are taken into account. In more general terms, it is noteworthy that the average plant species number recorded so far in European cemeteries is only 86 (Otves et al. 2016).

The taxa new for the Italian or regional flora are either young individuals born by natural dissemination from adult plants cultivated *in loco* for ornamental purposes (*Malus* ×*robusta* 'John Downie' and *Calocedrus decurrens* – Buldrini and Santini 2023), or adult individuals of species naturally growing in the cemetery area (*Epilobium ciliatum* and *Salvia haematodes*). This is proof of the continuous need for a floristic exploration of the territory, even of zones that apparently are the best known on a national scale, such as Emilia-Romagna (Alessandrini and Montanari 2022). It is also a proof of the potential that cemeteries have in introducing and spreading exotic species, since 3 of the 4 new species are allochthonous to the Italian flora (Portal to the Flora of Italy 2022). It is worth noting that the presence of *S. haematodes* is often underestimated, although it is possibly the dominant species in Italy within the group of *Salvia pratensis* L. (Pignatti et al. 2017–2019, Vol. III: 308, sub *S. pratensis* L. subsp. *haematodes* (L.) Briq.), thus a more careful examination may reveal that it is widespread throughout the national territory.

Concerning *Symphytum bohemicum* F.W.Schmidt, we provisionally accepted this identification, based on the corolla white-yellowish, the stems with few ramifications and the plant colour dark green (see Kobrlová et al. 2022), noting that this would be the first record of the species at the regional level. In fact, it is a simple new attribution

of populations formerly identified as *Symphytum officinale* L. (Pignatti et al. 2017–2019), therefore, further investigations are necessary to ascertain its real distribution in Emilia-Romagna. Similarly, for *Malus* ×*robusta* 'John Downie' given the horticultural origin of the mother plants and the probable hybridization with other species of the same group, at present we maintain the identification proposed (see Stace 1997; Johnson and More 2006; Sterry 2007; Brickell 2012; Wöhner et al. 2014), but there is a need to monitor the persistence and growth of the plantlets detected and further study the parent species, since it is a new taxon for the Italian flora.

The scarce influence on species number due to religion, as previously asserted by Rutkovska et al. (2011), and cemetery dimensions, as demonstrated by Nowińska et al. (2020), is apparently confirmed: 180 taxa in the Jewish cemetery on a surface of 1.0 ha, 205 taxa in the Catholic cemetery on a surface of 3.8 ha. Such a difference may rather be due, overall, to the diverse architectural and environmental characteristics of the areas (Kowarik et al. 2016). It has been demonstrated, in fact, that anthropic disturbance has a notable influence in shaping and selecting the flora of cemetery areas, favouring species with a short life cycle (Nowińska et al. 2020). Not surprisingly, in the Cimitero di San Cataldo annual species account for up to 40% of the total list and, in general, the species recorded are in many cases ruderal and typical of trampled areas (*Parietaria judaica* L., *Portulaca oleracea* L., *Polygonum rurivagum* Jord. ex Boreau, *Stellaria media* (L.) Vill. subsp. *media* etc.), or have a broad ecology, are common in many zones of continental Europe or are cosmopolitan (such as *Arabidopsis thaliana* (L.) Heynh., *Convolvulus sepium* L., *Cichorium intybus* L., *Trifolium repens* L.), or at least eurimediterranean (e.g. *Anisantha madritensis* (L.) Nevski subsp. *madritensis*, *Chondrilla juncea* L., *Leucanthemum vulgare* (Vaill.) Lam., *Malva setigera* K.F.Schimp. & Spenn.). Several of these species are quite frequent or even common also in the historical city centre of Modena, linked to disturbed places, uncultivated flowerbeds, backfill etc. (Danin et al. 2014, 2016; Buldrini et al. 2020). Other species, instead, testify to particular micro-ecological conditions: for example, *Allium pallens* L., *Carex caryophyllea* Latourr., *Convolvulus cantabrica* L. and *Spiranthes spiralis* (L.) Chevall. are typical of arid grasslands on draining or even rocky substrates (Pignatti et al. 2017–2019), while *Carex hirta* L. and *Mentha spicata* L. are indicators of a certain amount of soil moisture (Pignatti et al. 2005). It is probable that cracks and fissures in the tombstones mimic, in some respects, the fissures that can be observed in rocks and cliffs, whose vegetation is obviously selected by the very low presence of substrate and the strong heat, especially when these fissures are small and superficial and exposed to full sunlight. In such conditions, the species we observed are generally Mediterranean (e.g. *Allium roseum* L. subsp. *roseum*, *Asparagus officinalis* L. subsp. *officinalis*, *Ficus carica* L.), or at least short-lived therophytes (*Anisantha sterilis* (L.) Nevski). On the other hand, especially in zones 1c and 2, the grasslands, growing on a draining substrate for obvious sanitary reasons (Avramidou and Maio 2006), have a clearly arid character, with species like *Muscari comosum* (L.) Mill., *Ononis spinosa* L. subsp. *spinosa*, *Salvia verbenaca* L., *Scorpiurus subvillosus* L., *Thymus pulegioides* L. The essentially xeric conditions of the study area are also testified by the presence of some succulent species

(*Sedum* spp., *Petrosedum* spp.) among the chamaephytes and only one helophyte in the entire cemetery (*Phragmites australis* (Cav.) Trin. ex Steud. subsp. *australis*, that has a certain ecological amplitude – Pignatti et al. 2005, 2017–2019).

All the zones investigated in the Cimitero di San Cataldo are, to some extent, similar although they are very different in terms of history and number of visitors. Floristic richness varies among the single areas, probably depending on the number of environments that are present in each one (a strong correlation exists between these two parameters), as it is logical to expect and as already observed in the flora of the historical city centre of Modena (Buldrini et al. 2020). Such a similarity (at least ecological) is corroborated by the substantial constancy of the biological spectrum (Fig. 2): the diverse sectors analysed nearly always show analogous values for every life form, very close to those of the whole area (the only significant difference is a major presence of phanerophytes in zone 1b and a corresponding minor presence in zone 1c). Instead, differences are detectable in the chorological spectrum (Fig. 3), that shows a certain Mediterranean and thermophilous character in the flora of zone 1c and, to a lesser extent, of zone 2 (also characterised by wide grasslands), and a prevailing generalist character, with a tendency to floristic pollution, in zones 1a and 1b. The diversity analysis by Jaccard's index equally confirms the existence of considerable floristic differences, because the maximum similarity value is 0.373 (zones 1a–2), indicating that the two areas share only 37.3% of the species. These differences can be quite easily explained if we remember the diverse architectonic and physiognomic characters of the single zones: grasslands, monumental tombs, gravel driveways, hedgerows, and some ornamental trees in zone 1a, monumental tombs and gravel driveways in zone 1b, a wide grassland closed by a brick wall and a hedgerow with various large stones closing the small wells where the bones of ancient corpses are buried in zone 1c, grasslands, gravel driveways, and a few hedgerows in zone 2.

The number of exotic species (16.9% of the list) seems lower than in the cemeteries of central Europe: in Poland, for example, a study on 78 cemetery areas in the southeast of the country revealed the presence of 19–36% of allochthonous species (Czarna and Nowińska 2011; Nowińska et al. 2020). In some Poznań cemeteries, allochthonous taxa accounted for more than 50% of the list (Czarna et al. 2011; Czarna 2016a, b) although, in some cases, they were only 12–15% of the list (Celka and Żywika 2004; Sigiel-Dopierała and Jagodziński 2011). It is worth noting that the percentage of exotic species of zones 1a and 2 is very similar (14.7% *versus* 16.7%, respectively), whereas zone 1c is the least floristically polluted (9.8% of exotic species) and zone 1b the most polluted one (22.0%). For zone 2, the result is not surprising, since in the Jewish culture the use of adorning tombs with flowers or ornamental cultivated species does not exist (Palacz 1996), therefore exotic species always constitute a small fraction of the list even in other European countries (e.g., Czarna and Nowińska 2010). For zone 1c, the low value is probably due to the age of this sector, dating back to the foundation of the entire cemetery complex; indeed, the grassland is nearly 250 years old and reflects a prolonged stability. It seems clear, anyway, that the historical cemetery of Modena has, in some respects, a conservative behaviour from a floristic viewpoint,

exactly as observed in the historical city centre (Buldrini et al. 2020); this fact could be due to the never invasive nor intense human presence, the moderate disturbance imposed by lawn mowing, and the substantial stability of burial areas (Avramidou and Maio 2006). The different results obtained in Poland may be the effect of a colder continental climate (Kowarik 1995; Pyšek 1998; Lososová et al. 2012), with consequent absence of the autochthonous Mediterranean and thermophilous floristic components (cfr. Mirek et al. 2002) that could, at least partially, prevent the establishment of some allochthonous species, particularly those typical of warm climates.

The number of red-listed species in the monumental cemetery of Modena is very low (2.6% of the total), but comparable to 2.8–3.6% of protected species found in the cemeteries of the urban area of Poznań (Czarna 2016a, b). In other European countries, protected species can account for higher proportions of the floristic list, e.g. 5.6–5.7% in southern Ukraine (Moysiyenko et al. 2021; Skobel et al. 2023) and in the Ostrów Wielkopolski area (central south-western Poland; Celka and Żywika 2004). In Hungary, they represented an average of 0.12 ± 1.47% (calculated on a global list of 991 cemeteries) and the number of protected species in the single cemeteries varied from 1 to 13 (Löki et al. 2020). It should be pointed out, however, that in the above-mentioned countries protected species are often planted for their ornamental value, therefore, the cemetery would be a secondary station of anthropogenic origin (Sigiel-Dopierała and Jagodziński 2011); only in some cases they spread spontaneously in the burial grounds, coming from adjacent zones (e.g. Nowińska et al. 2020). In the Cimitero di San Cataldo, the only protected species cultivated for ornament are *Ilex aquifolium* and *Taxus baccata* (both native to the Italian territory), which spread naturally in the studied area by ornithochorous dispersal; the others simply arrived by spontaneous colonisation. The persistence of some of them (e.g. *Bellevalia romana* and *Spiranthes spiralis*) may be due to the moderate, periodical disturbance imposed by mowing, that allows regular flowering and dissemination, as already observed for other grassland species typical of initial or intermediate stages of the ecological succession (Buldrini and Dallai 2011; Buldrini et al. 2013). Regarding protected species, the most interesting area is zone 2, where 5 of the 7 protected species were observed, all of them spontaneous. Among them, *S. spiralis* is of particular importance as it is rare in all of northern Italy (Pignatti et al. 2017–2019) and especially in the Po valley (Alessandrini and Bonafede 1996; Tedaldi 2000; Piccoli et al. 2014); it is, by contrast, quite frequent in arid grasslands of the hill belt. More than 50 individuals of this species were found in zone 2. Its presence, together with that of *Anacamptis morio* (ca. 25 individuals) and *B. romana*, is a sure indicator of good naturalness and scarce disturbance of the study site.

Conclusions

The flora of ancient monumental cemeteries is of high interest from a biological and ecological viewpoint. The variety of habitats and substrates and the moderate disturbance permit the development of a rich flora, where allochthonous and protected

species can grow together within a restricted area (a few dozen meters) and the invasive ones do not behave as such, at least in the present case. The environmental and ecological conditions of a monumental cemetery can show some similarities to those of ancient city centres, whose conservative value from a floristic standpoint has already been verified. It is, therefore, desirable that other monumental cemeteries be investigated, both in Italy and in other European countries, to better understand their role in preserving the native flora and in spreading the exotic one.

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Supplementary material 1

Floristic list of the study area

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Data type: PDF file

Explanation note: List of taxa found in the areas investigated. Zone 1a: Catholic cemetery, monumental part; zone 1b: Catholic cemetery, ancient tombs disposed all along the southern perimeter wall of the cemetery complex; zone 1c: Catholic cemetery, grasslands of the ancient ossuary; zone 2: Jewish cemetery.

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